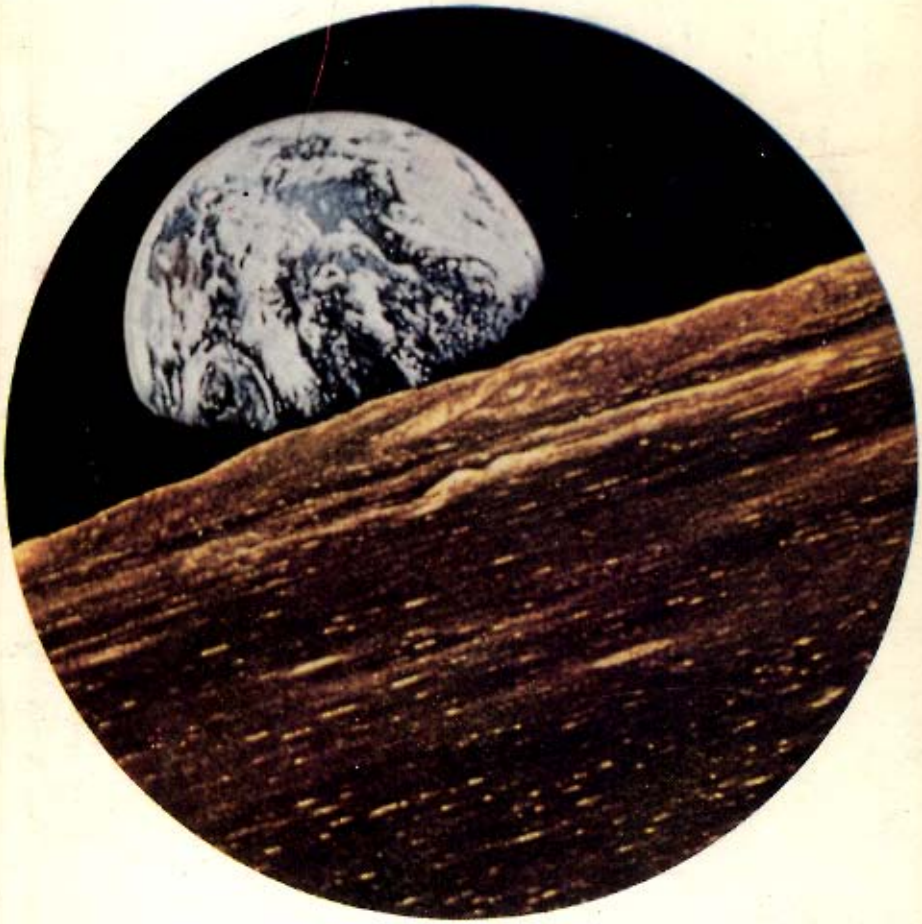
1975
Yearbook of
ASTRONOMY

Edited by Patrick Moore



1975 Yearbook of Astronomy

Edited by

PATRICK MOORE

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Editor's Foreword

There is really very little to be said as a Foreword to this, the fourteenth issue of the *Yearbook*. The recipe has been judged to be acceptable in the past; this version in unchanged in style; once again we have some of our familiar contributors, with some new ones also, and once again Dr. Porter has provided the information for all the essential sections.

PATRICK MOORE

Selsey, 1974.

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—*The Newtonian Flat and its Mounting:* 1972.
WRIGHT, H. N. D. *The Surface of Saturn:* 1964.

Preface

New readers will find that all the information in this *Yearbook* is given in diagrammatic or descriptive form; the positions of the planets may easily be found on the specially designed star charts, while the monthly notes describe the movements of the planets, and give details of other astronomical phenomena that may be observed from these latitudes. The reader who needs more detailed information will find *Norton's Star Atlas* (Gall and Inglis) an invaluable guide, while more precise positions of the planets and their satellites, together with predictions of occultations, meteor showers and periodic comets may be found in the *Handbook* of the British Astronomical Association. A somewhat similar publication is the *Observer's Handbook* of the Royal Astronomical Society of Canada, and readers will also find details of forthcoming events given in the American *Sky and Telescope* (which also publishes complete details of all occultations visible in North America).

Important Note

The star charts are drawn, and the notes are, in general, designed for use in latitude 52 degrees north, but may be used without alteration throughout the British Isles, and (except in the case of eclipses and occultations) in other countries of similar north latitude.

The times given on the star charts and in the Monthly Notes are generally given as local times, using the 24-hour clock, the day beginning at midnight. Ignoring small differences of longitude, this local time may be taken as Greenwich Mean Time (G.M.T.) in the British Isles, or as the appropriate Standard Time in other

Time Zones. If Summer Time is in use, the clocks will have been advanced by one hour, and this hour must be subtracted from the clock time to give G.M.T.

In Great Britain and N. Ireland, Summer Time will be in force in 1975 from 16 March 02^h to 26 October 02^h.

The times of a few events (e.g., eclipses) are given in G.M.T., and this may be converted to Local Mean Time by subtracting the west longitude (or adding the east longitude).

Local Mean Time = G.M.T. – West Longitude

Similarly,

Eastern Standard Time = G.M.T. – 5 hours,

Central Standard Time = G.M.T. – 6 hours, etc.

PART ONE

Events of 1975

Monthly Charts and Astronomical Phenomena

Notes on the Star Charts

The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 20 to 45 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitude of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of 62½ degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the coverage is 200 degrees in azimuth, from a little north of east

(top left) to a little north of west (top right). The two lower charts show the northern sky, from a little south of west (lower left) to a little south of east (lower right). There is thus an overlap east and west.

The charts have been drawn for a latitude of 52 degrees, but may be taken without appreciable error to apply to all parts of the British Isles. They will also be equally suitable for any other part of the world having a north latitude of about 52 degrees – e.g. parts of Europe and Asia, and Canada. In such cases the times given must be taken as local time, and not G.M.T., which applies only to the British Isles.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, which amounts to two hours in a month. Hence, the twelve sets of charts are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. This information is summarized in the following table, which gives the number of the star chart to be used for any given month and time.

G.M.T.	16^h	18^h	20^h	22^h	0^h	2^h	4^h	6^h
January	10	11	12	1	2	3	4	5
February		12	1	2	3	4	5	6
March			2	3	4	5	6	
April			3	4	5	6		
May			4	5	6	7		
June			5	6	7			
July			6	7	8	9		
August			7	8	9	10	11	
September		7	8	9	10	11	12	
October		8	9	10	11	12	1	
November	8	9	10	11	12	1	2	3
December	9	10	11	12	1	2	3	4

The charts are drawn to scale, and estimates of altitude and azimuth may be made from them. These values will necessarily be mere approximations, since no observer will be exactly on the meridian of Greenwich at 52 degrees latitude, but they will generally serve for the identification of stars and planets. The horizontal measurements, marked at every ten degrees, give the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to $62\frac{1}{2}$ degrees.

The ecliptic is drawn as a broken line on which the longitude is marked at every ten degrees; the positions of the planets at any time are then easily found by reference to the table immediately following the star charts on page 48.

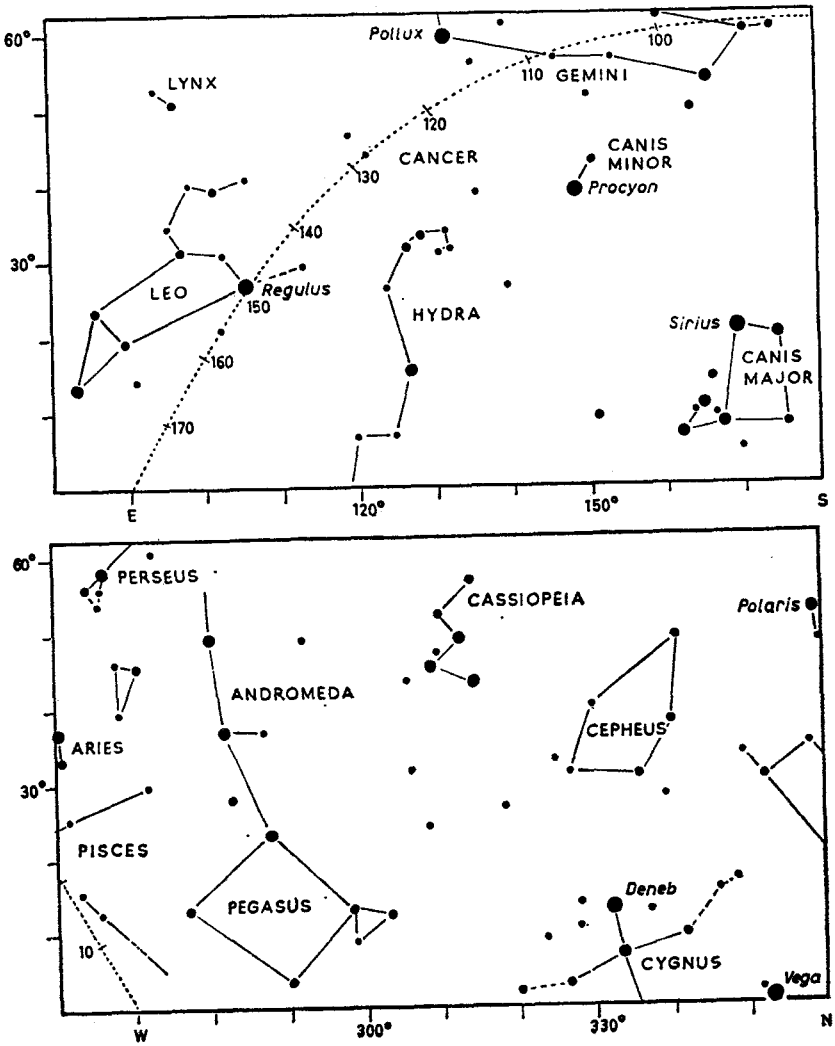
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These high-altitude stars, being nearer the pole, move more slowly across the sky, and a different kind of map may therefore be used. These overhead stars are given separately on pages 44 and 45, the entire year being covered at one opening. Each of the four maps shows the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith in latitude 52 degrees is indicated by a cross, and this cross also marks the centre of a circle which is 35 degrees from the zenith, and which therefore indicates an altitude of 55 degrees; there is thus a small overlap with the main charts.

The broken line leading from north to south is numbered to indicate the corresponding main chart. Thus on page 44 the N–S line numbered 6 is to be regarded as an extension of the S line of chart 6 on pages 30 and 31, and at the top of these pages are given dates and times which are appropriate.

The scale is the same on all the charts (approximately 25 degrees to the inch), but the overhead stars are plotted as a true map on a conical projection, and are not simple graphs like the main charts.

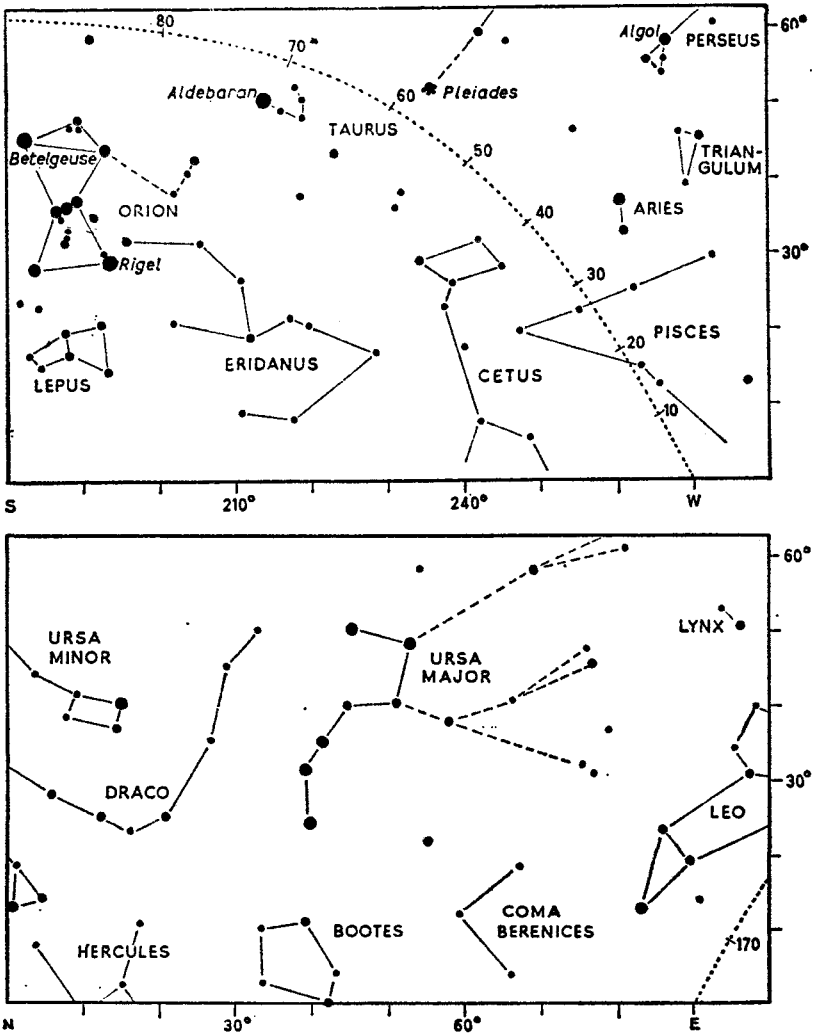
1L

October 6 at	5h	October 21 at	4h
November 6 at	3h	November 21 at	2h
December 6 at	1h	December 21 at	midnight
January 6 at	23h	January 21 at	22h
February 6 at	21h	February 21 at	20h



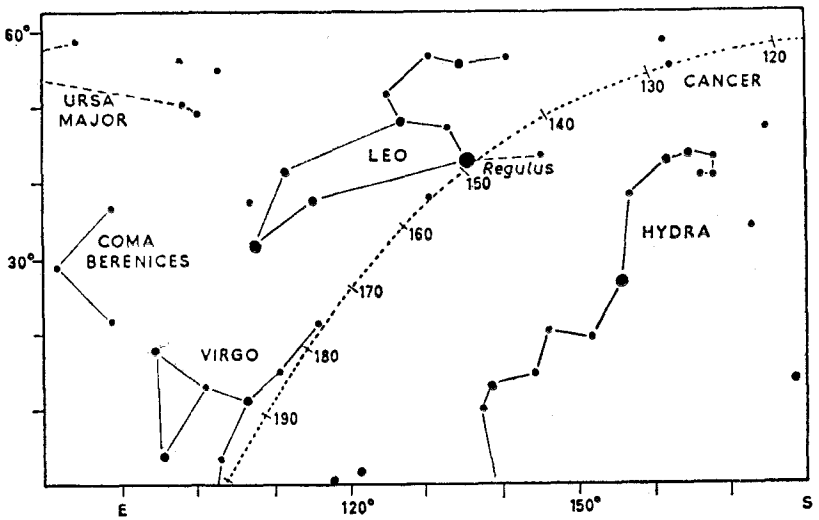
October 6 at	5h	October 21 at	4h
November 6 at	3h	November 21 at	2h
December 6 at	1h	December 21 at	midnight
January 6 at	23h	January 21 at	22h
February 6 at	21h	February 21 at	20h

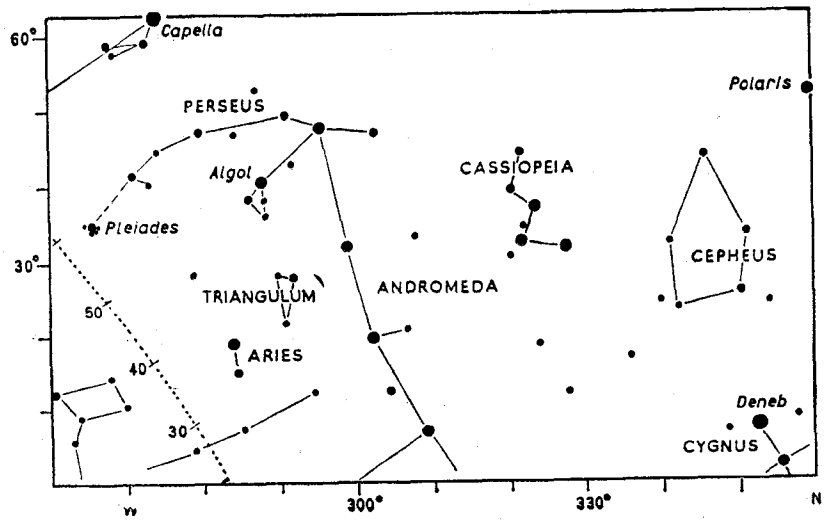
1R



2L

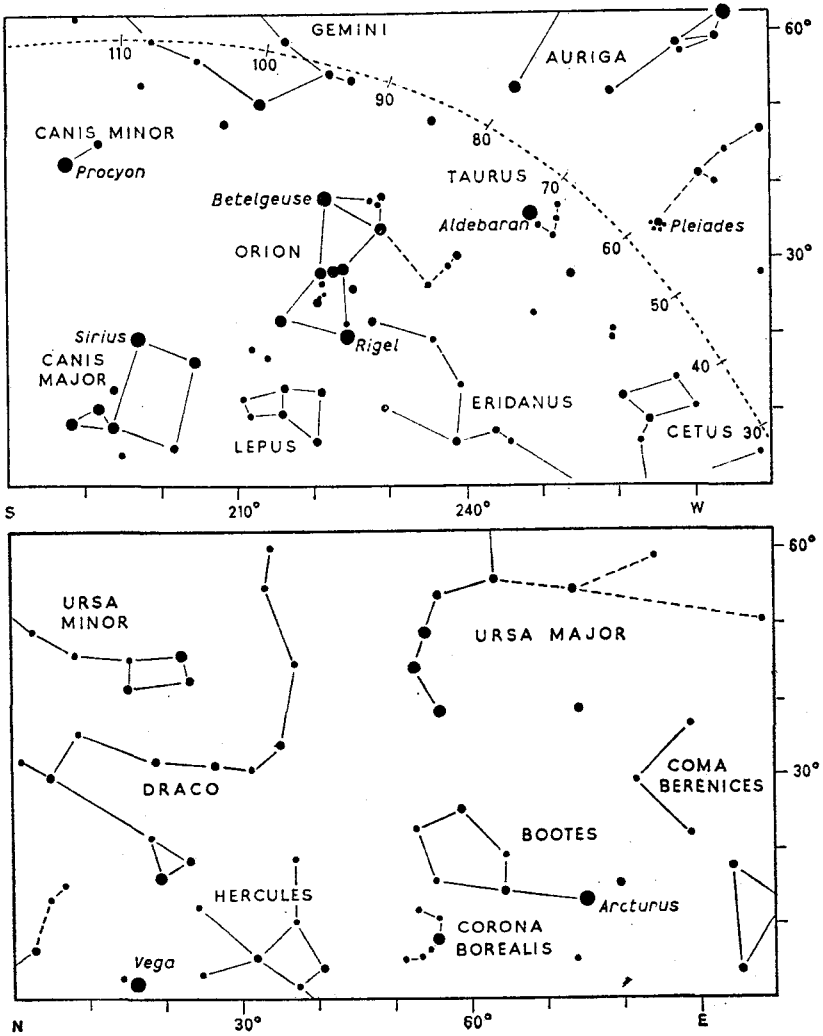
November 6 at 5h	November 21 at 4h
December 6 at 3h	December 21 at 2h
January 6 at 1h	January 21 at midnight
February 6 at 23h	February 21 at 22h
March 6 at 21h	March 21 at 20h





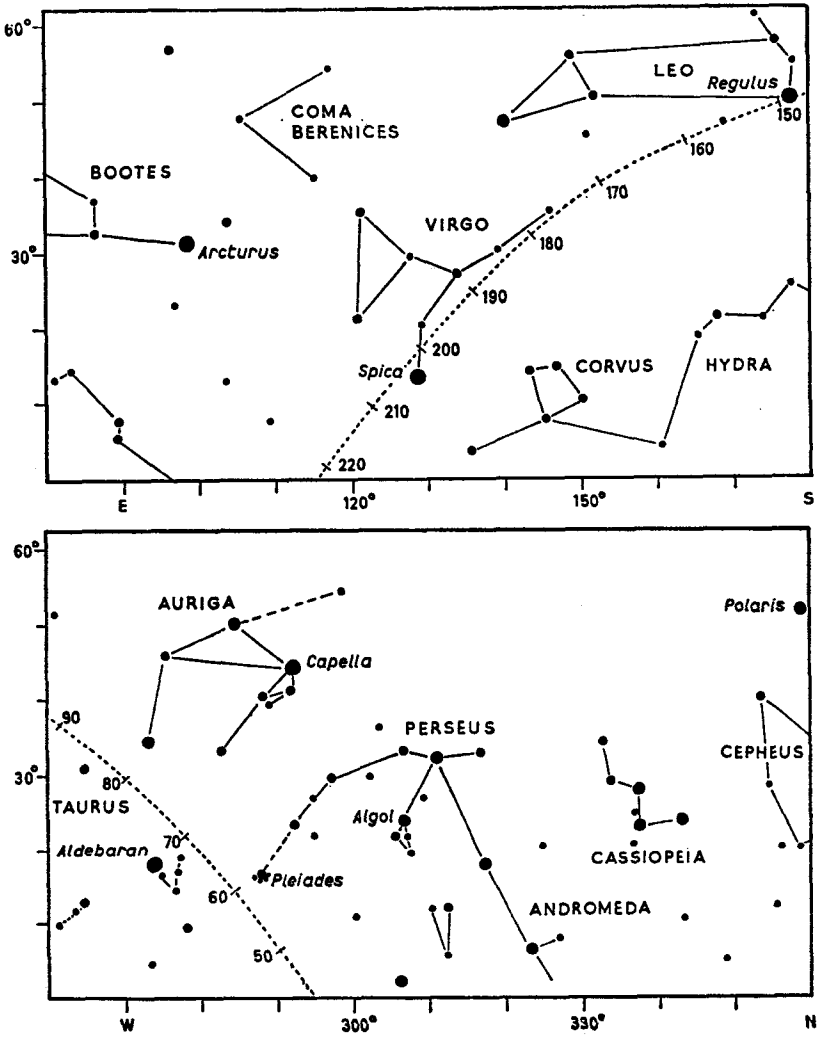
November 6 at	5h	November 21 at	4h
December 6 at	3h	December 21 at	2h
January 6 at	1h	January 21 at	midnight
February 6 at	23h	February 21 at	22h
March 6 at	21h	March 21 at	20h

2R



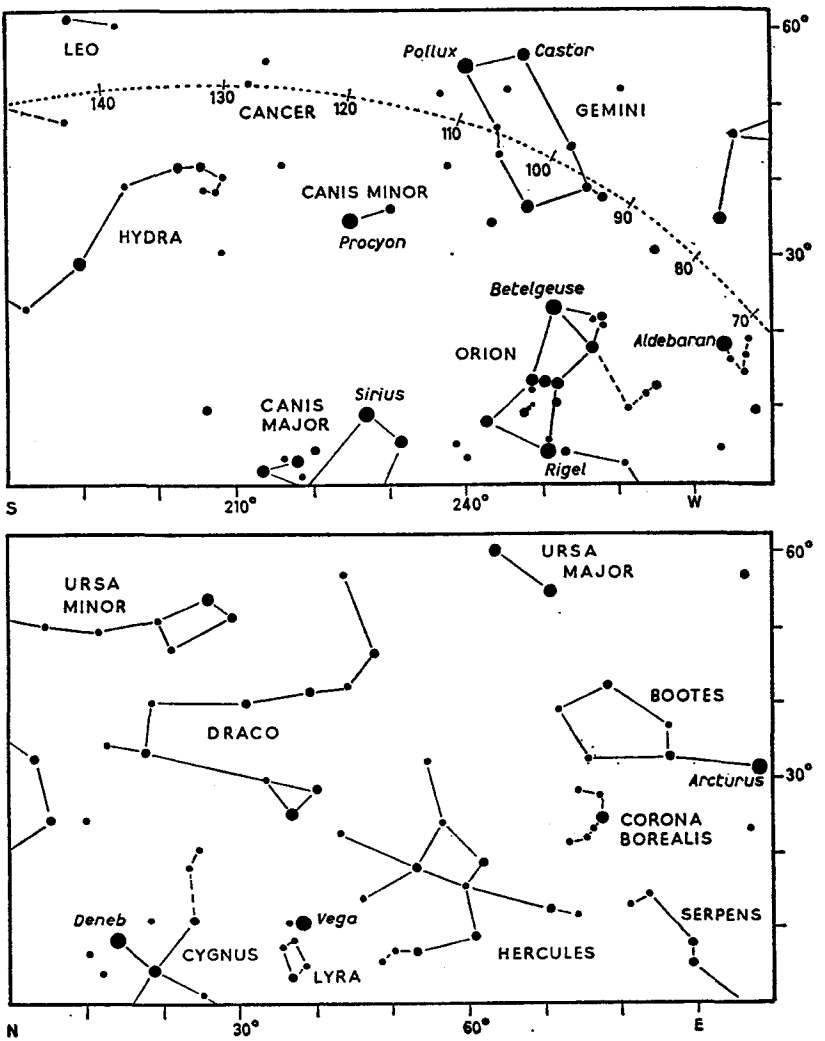
3L

December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h



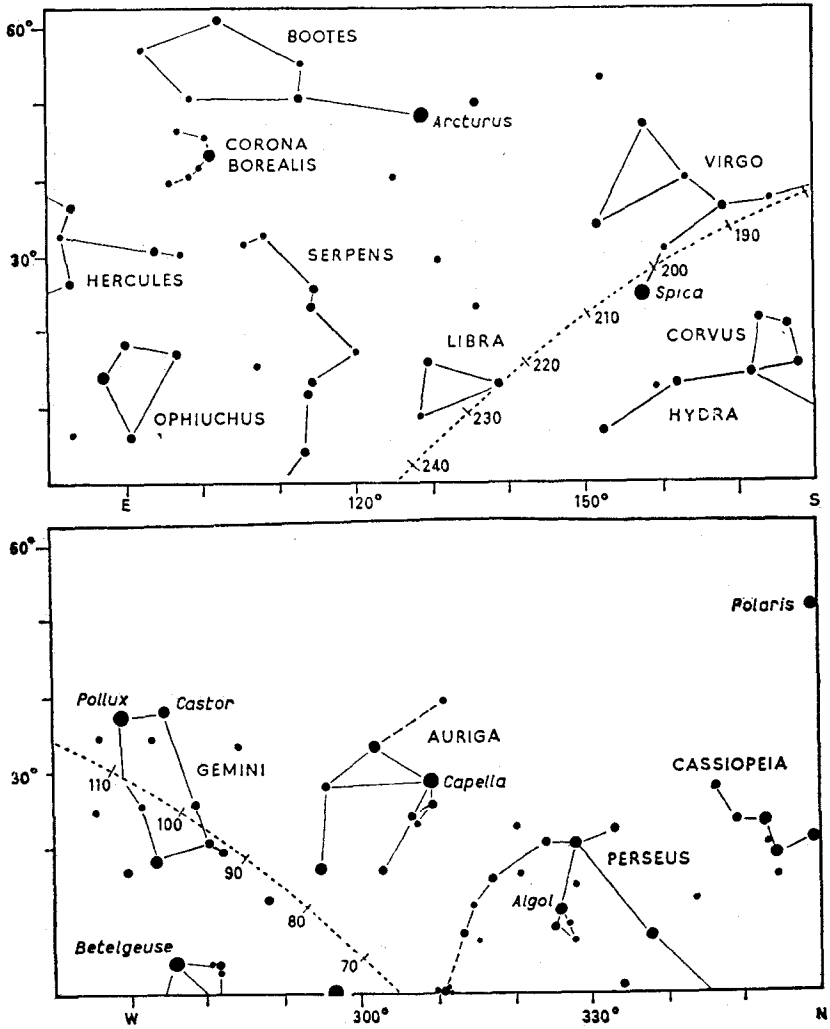
December 6 at	5h	December 21 at	4h
January 6 at	3h	January 21 at	2h
February 6 at	1h	February 21 at	midnight
March 6 at	23h	March 21 at	22h
April 6 at	21h	April 21 at	20h

3R



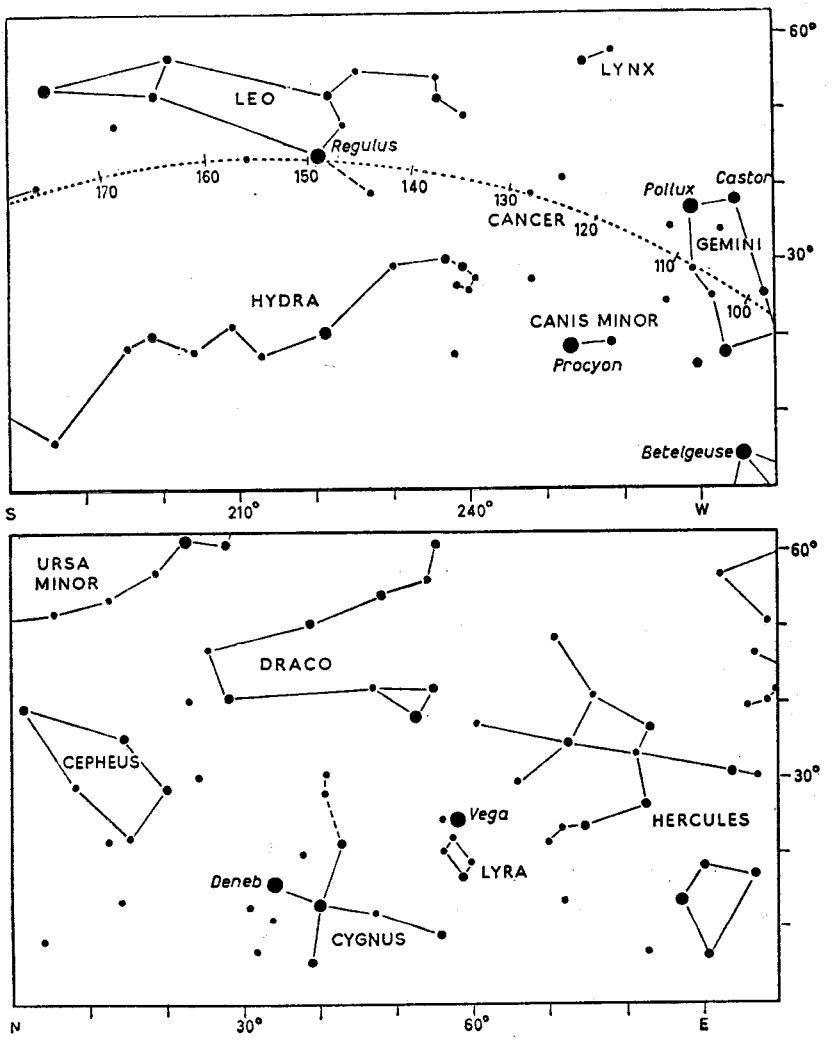
4L

January 6 at 5h	January 21 at 4h
February 6 at 3h	February 21 at 2h
March 6 at 1h	March 21 at midnight
April 6 at 23h	April 21 at 22h
May 6 at 21h	May 21 at 20h



January 6 at	5h	January 21 at	4h
February 6 at	3h	February 21 at	2h
March 6 at	1h	March 21 at	midnight
April 6 at	23h	April 21 at	22h
May 6 at	21h	May 21 at	20h

4R



5L

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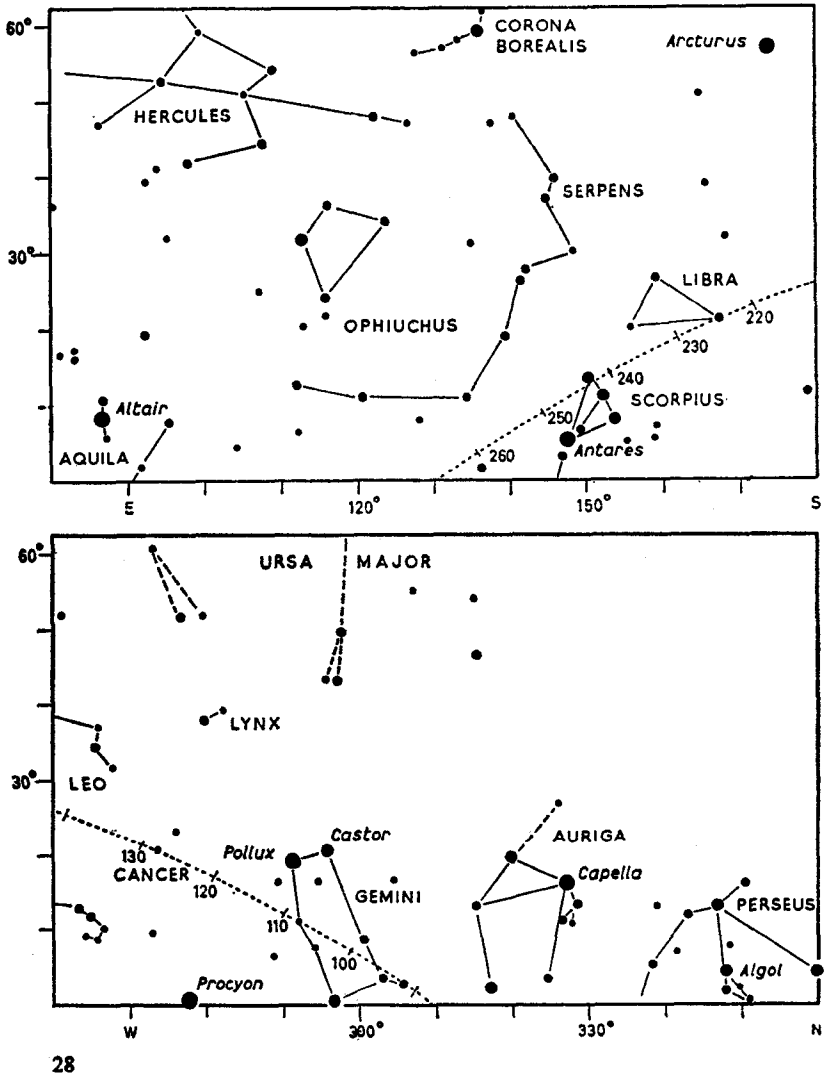
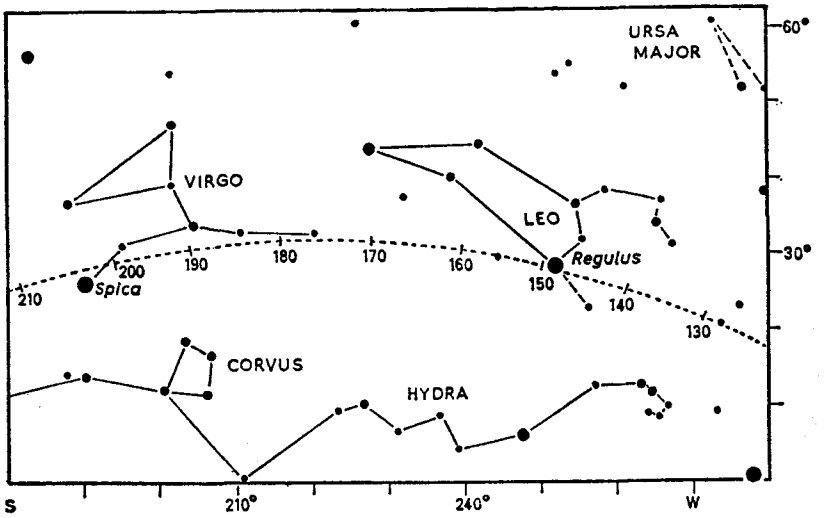
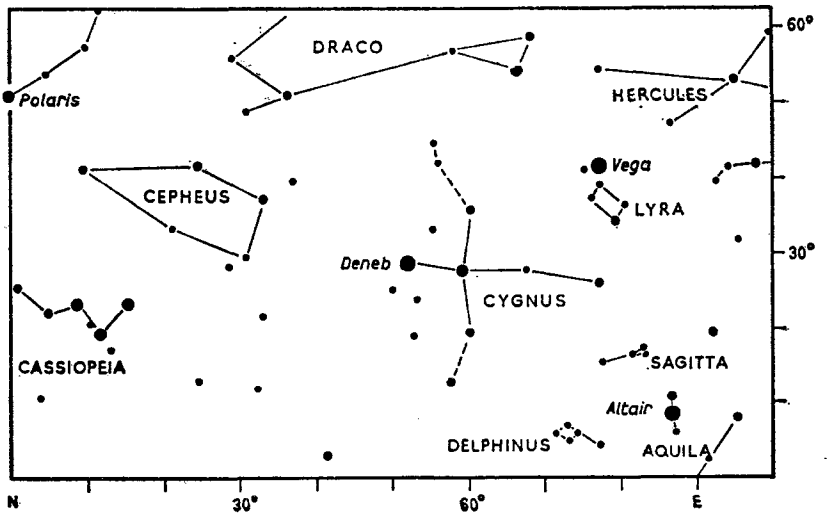
March 6 at 3h	March 21 at 2h
April 6 at 1h	April 21 at midnight
May 6 at 23h	May 21 at 22h



January 6 at	7h	January 21 at	6h
February 6 at	5h	February 21 at	4h
March 6 at	3h	March 21 at	2h
April 6 at	1h	April 21 at	midnight
May 6 at	23h	May 21 at	22h

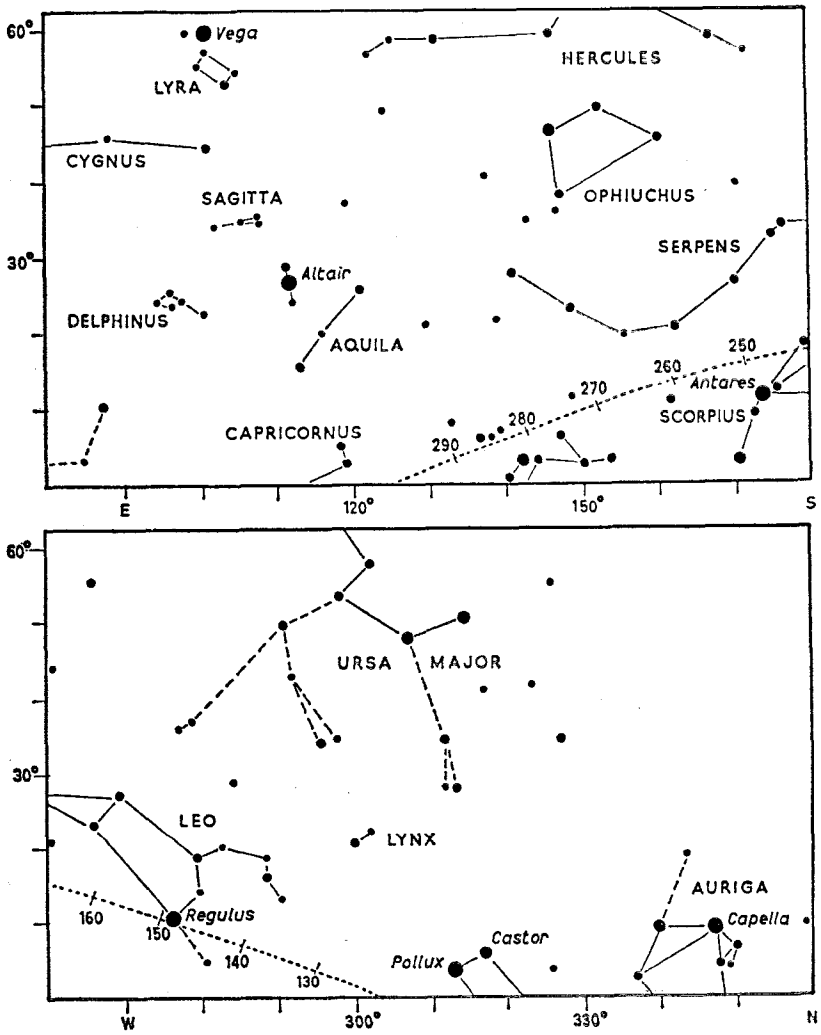
5R





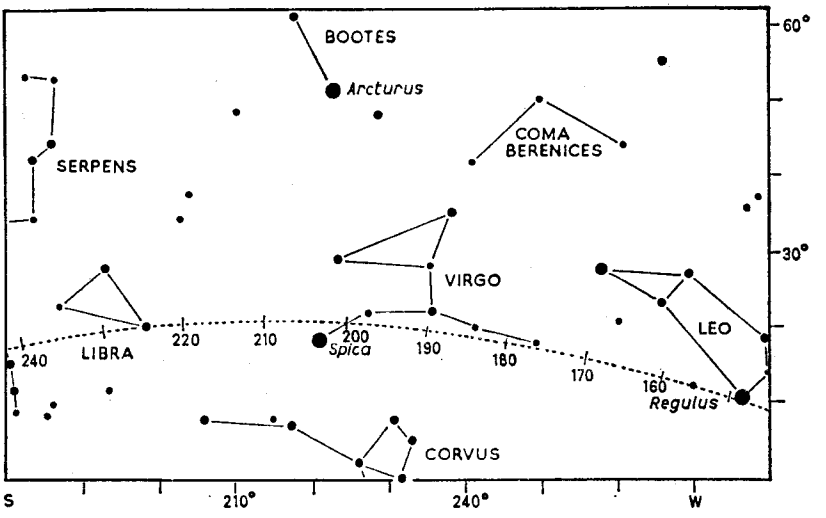
6L

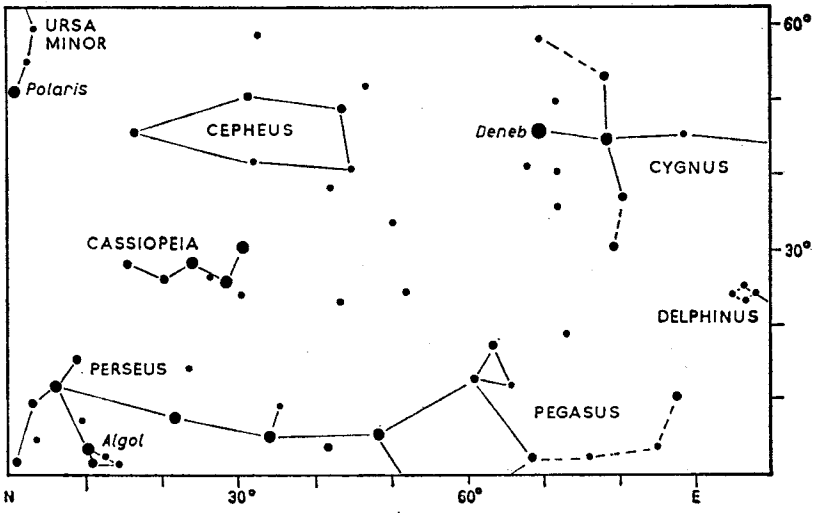
March 6 at 5h	March 21 at 4h
April 6 at 3h	April 21 at 2h
May 6 at 1h	May 21 at midnight
June 6 at 23h	June 21 at 22h
July 6 at 21h	July 21 at 20h



March 6 at	5h	March 21 at	4h
April 6 at	3h	April 21 at	2h
May 6 at	1h	May 21 at	midnight
June 6 at	23h	June 21 at	22h
July 6 at	21h	July 21 at	20h

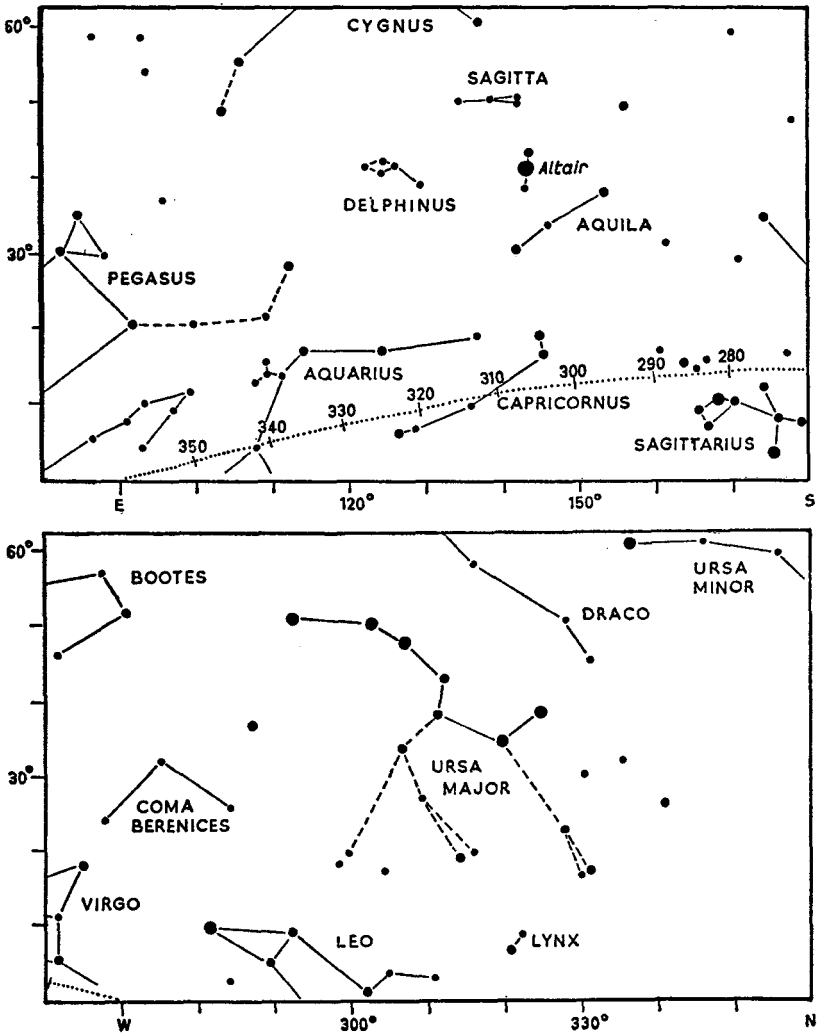
6R



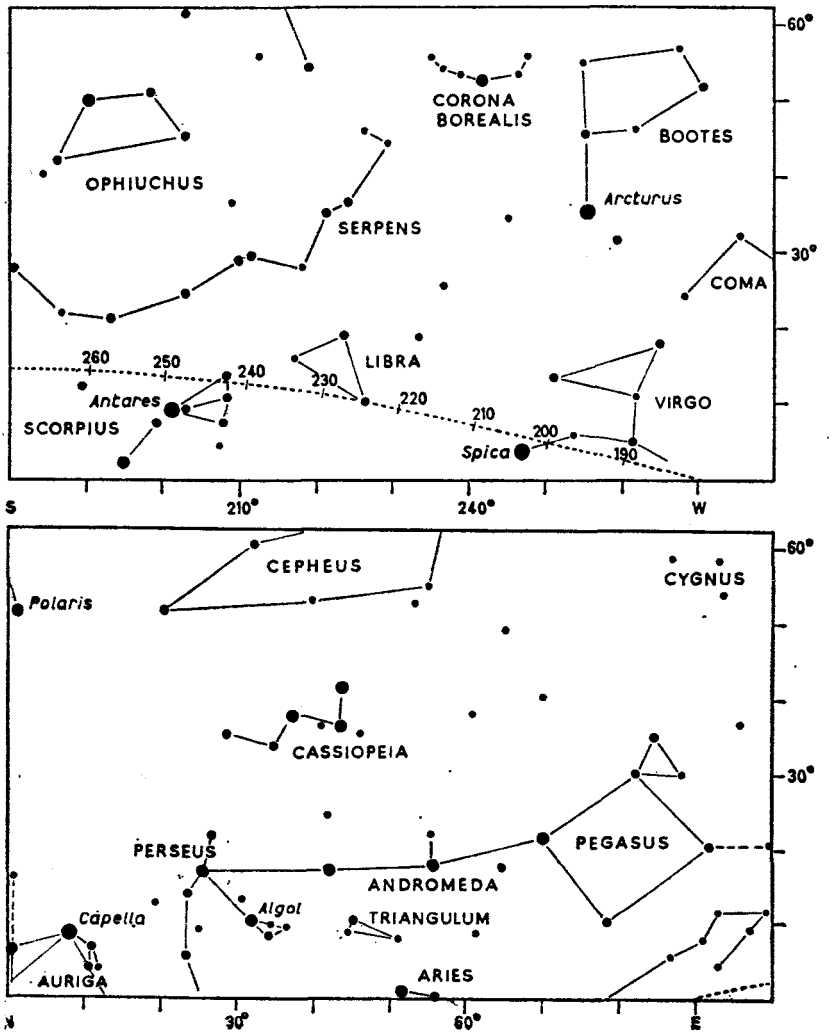


7L

May 6 at 3h	May 21 at 2h
June 6 at 1h	June 21 at midnight
July 6 at 23h	July 21 at 22h
August 6 at 21h	August 21 at 20h
September 6 at 19h	September 21 at 18h

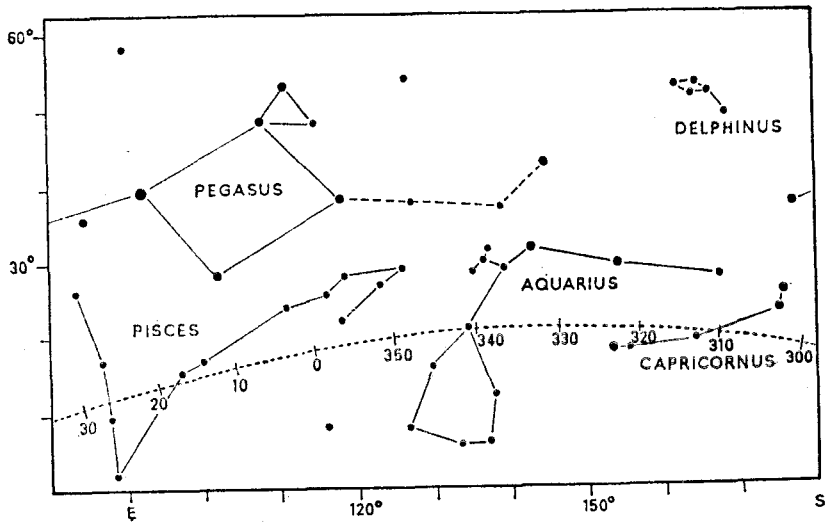


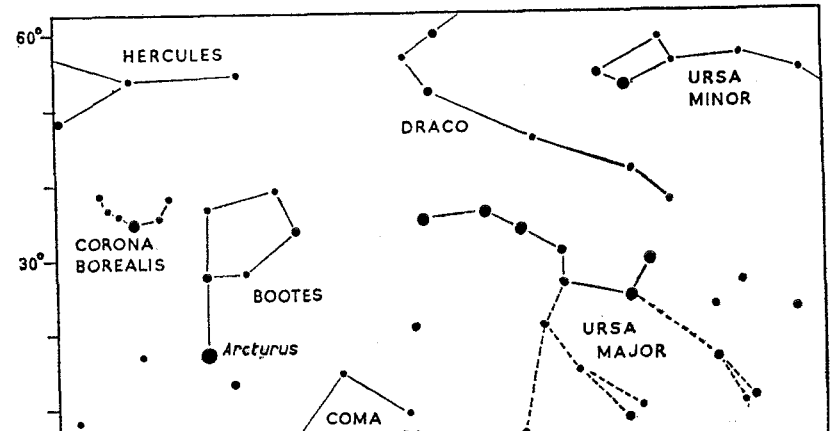
May 6 at 3h	May 21 at 2h	**7R**
June 6 at 1h	June 21 at midnight	
July 6 at 23h	July 21 at 22h	
August 6 at 21h	August 21 at 20h	
September 6 at 19h	September 21 at 18h	



8L

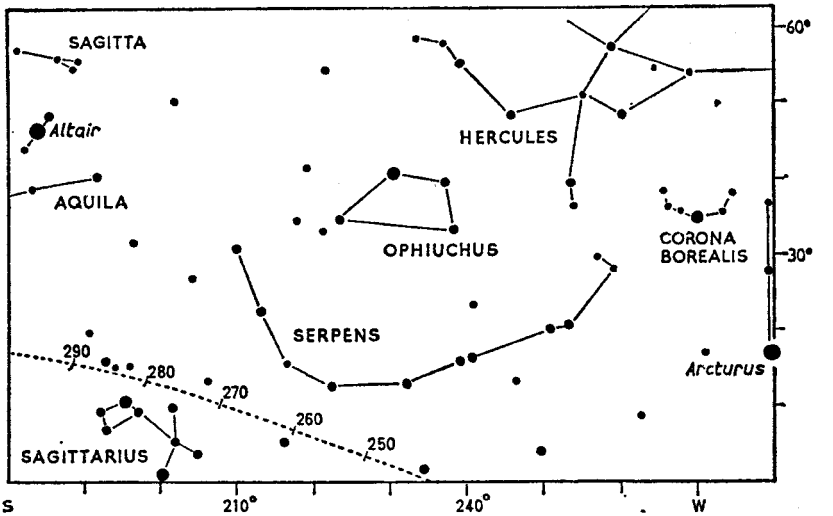
July 6 at 1h	July 21 at midnight
August 6 at 23h	August 21 at 22h
September 6 at 21h	September 21 at 20h
October 6 at 19h	October 21 at 18h
November 6 at 17h	November 21 at 16h

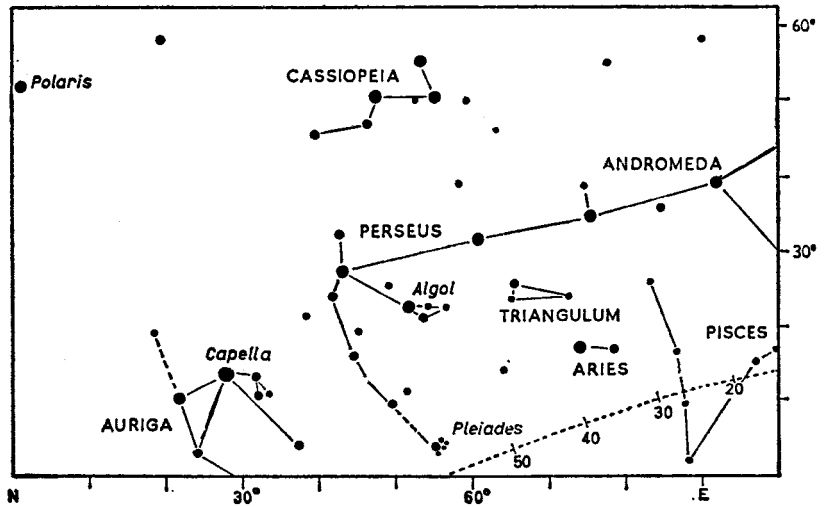




July 6 at 1h	July 21 at midnight
August 6 at 23h	August 21 at 22h
September 6 at 21h	September 21 at 20h
October 6 at 19h	October 21 at 18h
November 6 at 17h	November 21 at 16h

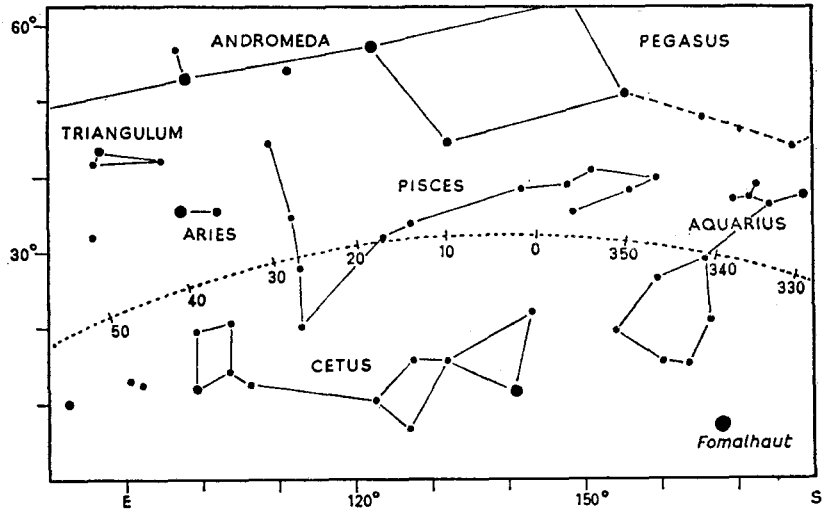
8R

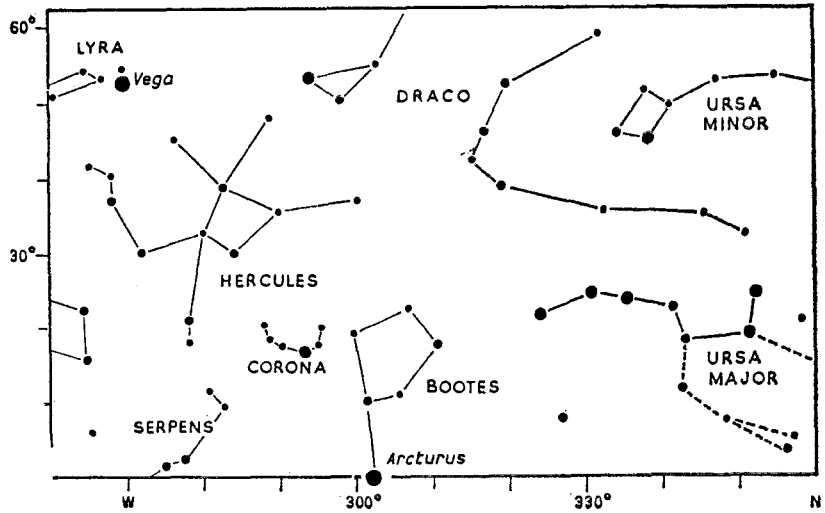




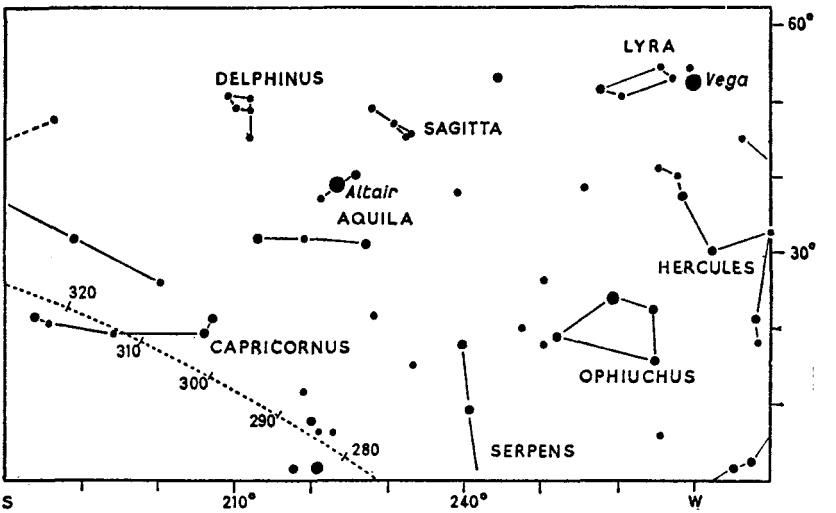
9L

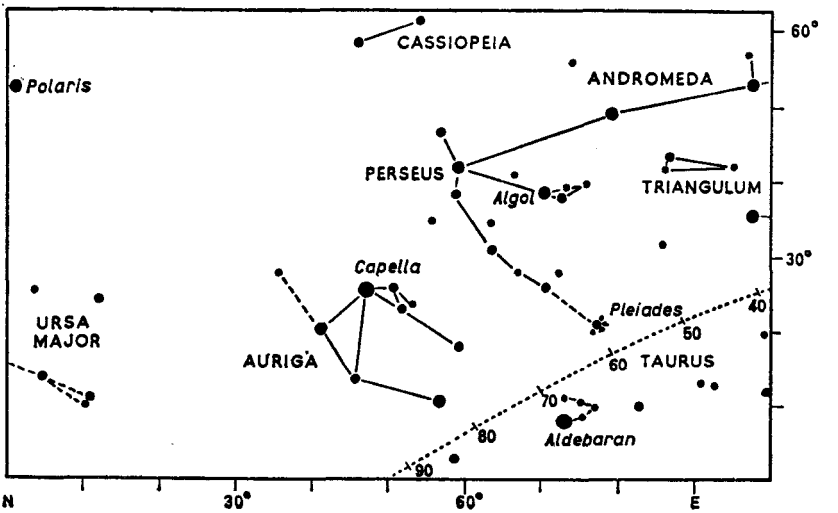
August 6 at 1h	August 21 at midnight
September 6 at 23h	September 21 at 22h
October 6 at 21h	October 21 at 20h
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h





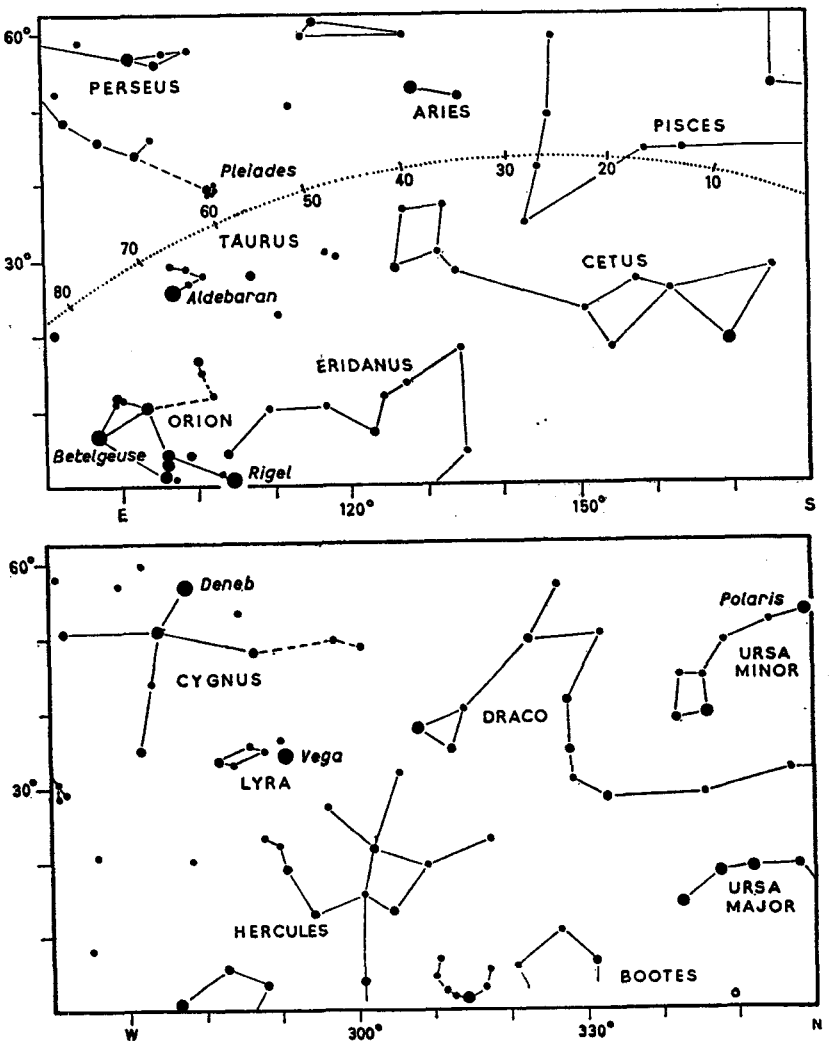
August 6 at 1h	August 21 at midnight	**9R**
September 6 at 23h	September 21 at 22h	
October 6 at 21h	October 21 at 20h	
November 6 at 19h	November 21 at 18h	
December 6 at 17h	December 21 at 16h	





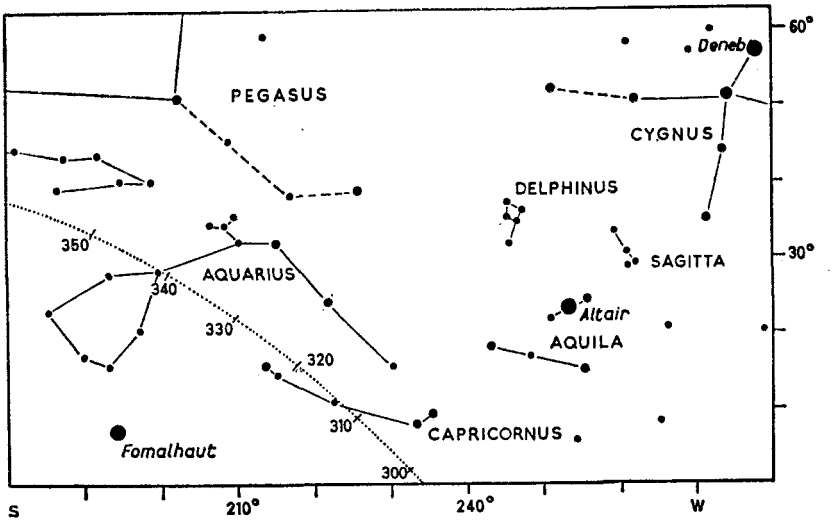
10L

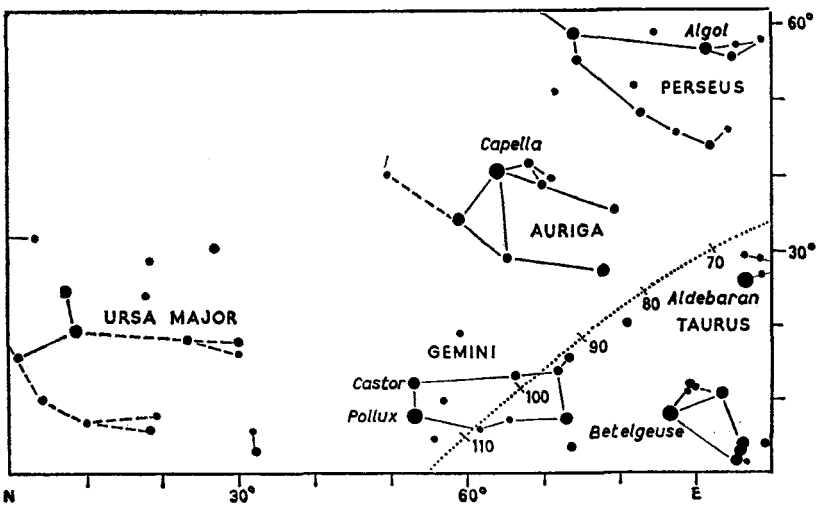
August 6 at 3h	August 21 at 2h
September 6 at 1h	September 21 at midnight
October 6 at 23h	October 21 at 22h
November 6 at 21h	November 21 at 20h
December 6 at 19h	December 21 at 18h



August 6 at 3h	August 21 at 2h
September 6 at 1h	September 21 at midnight
October 6 at 23h	October 21 at 22h
November 6 at 21h	November 21 at 20h
December 6 at 19h	December 21 at 18h

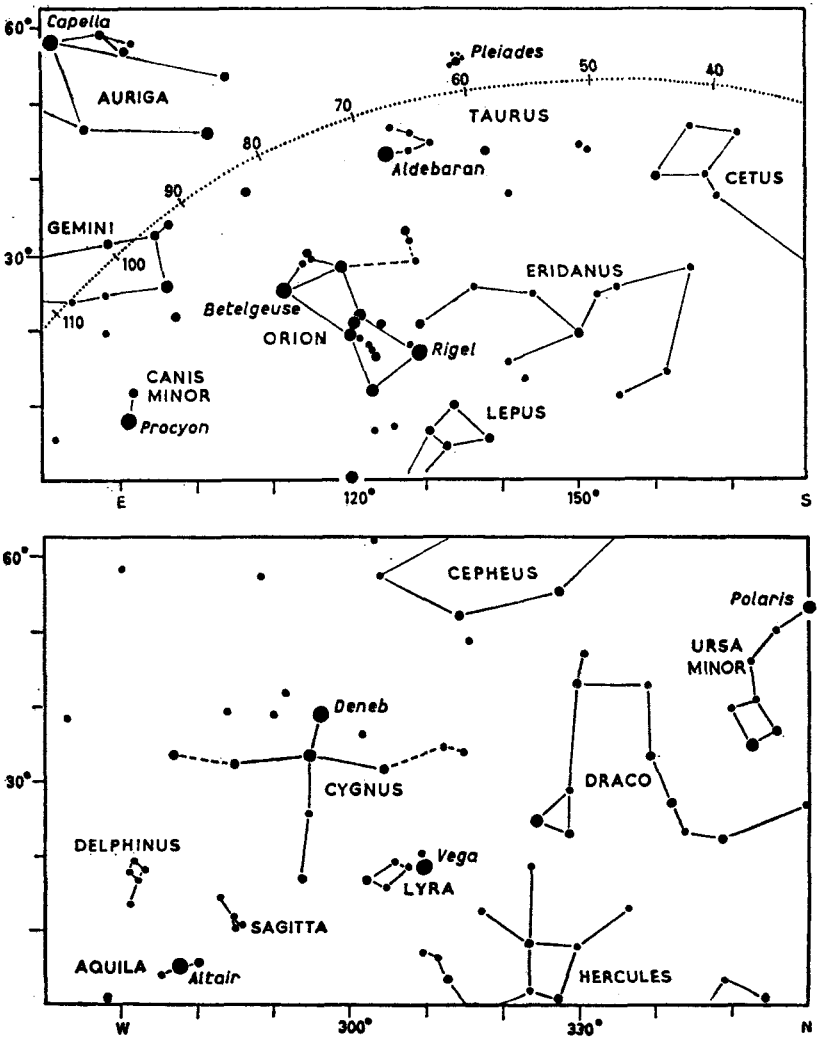
10R





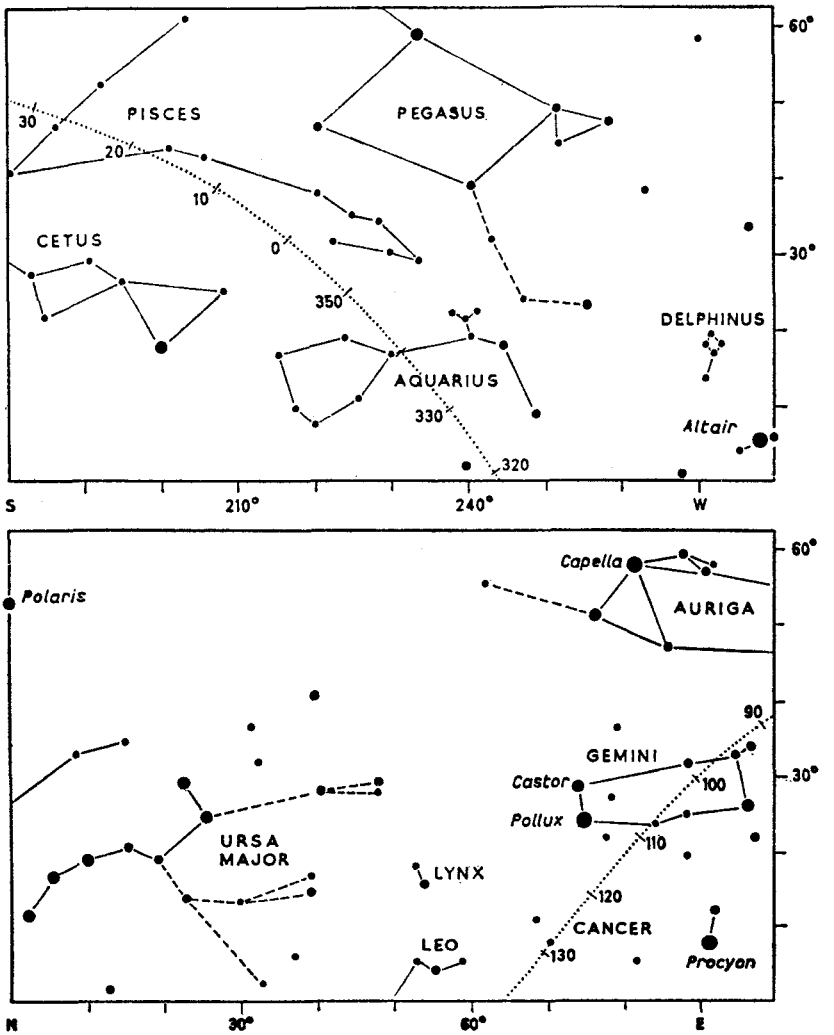
11L

September 6 at 3h	September 21 at 2h
October 6 at 1h	October 21 at midnight
November 6 at 23h	November 21 at 22h
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h



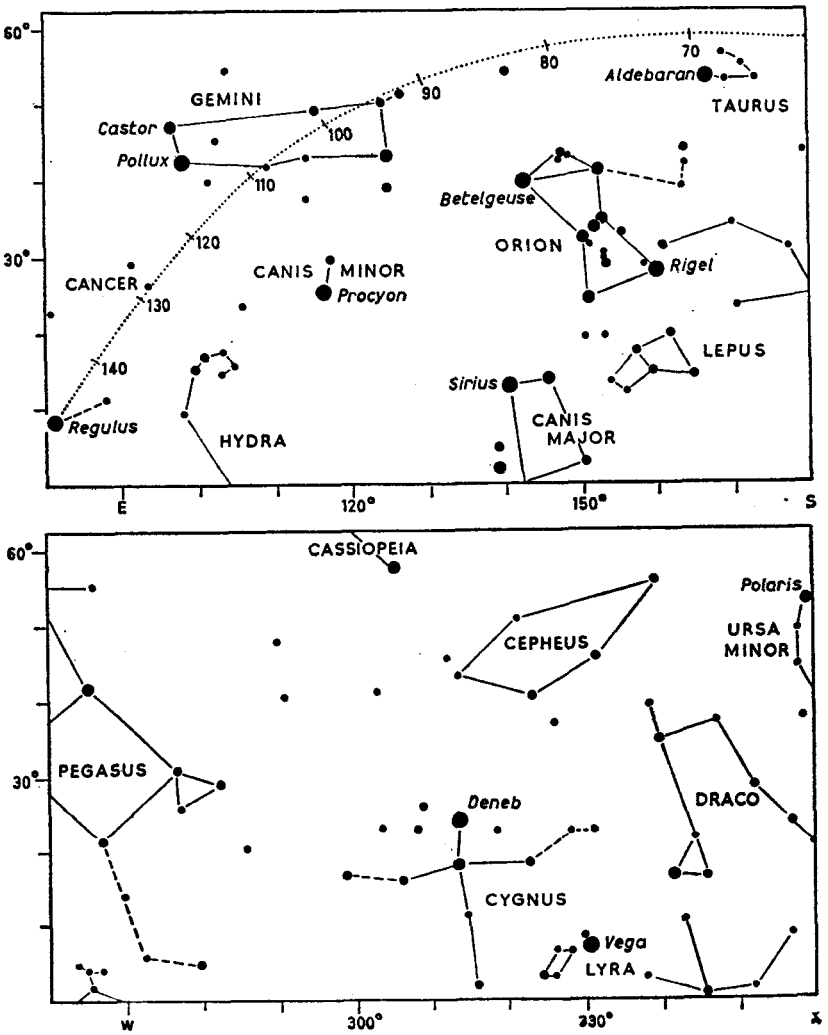
September 6 at 3h	September 21 at 2h
October 6 at 1h	October 21 at midnight
November 6 at 23h	November 21 at 22h
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h

11R

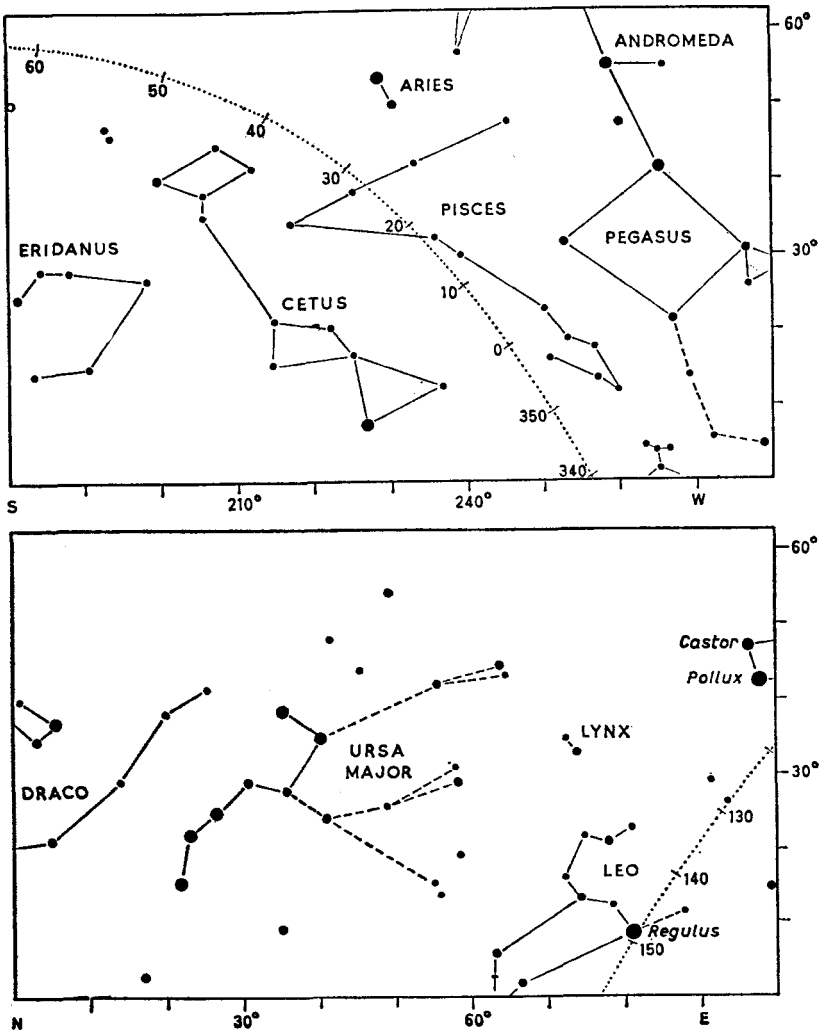


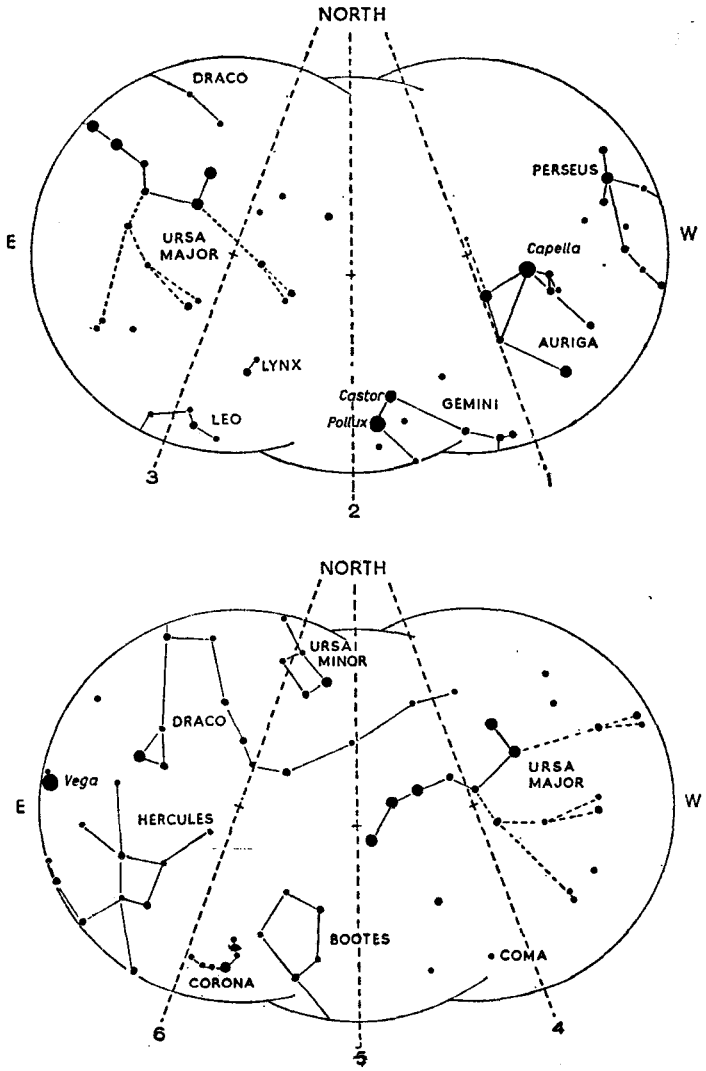
12L

October 6 at 3h	October 21 at 2h
November 6 at 1h	November 21 at midnight
December 6 at 23h	December 21 at 22h
January 6 at 21h	January 21 at 20h
February 6 at 19h	February 21 at 18h

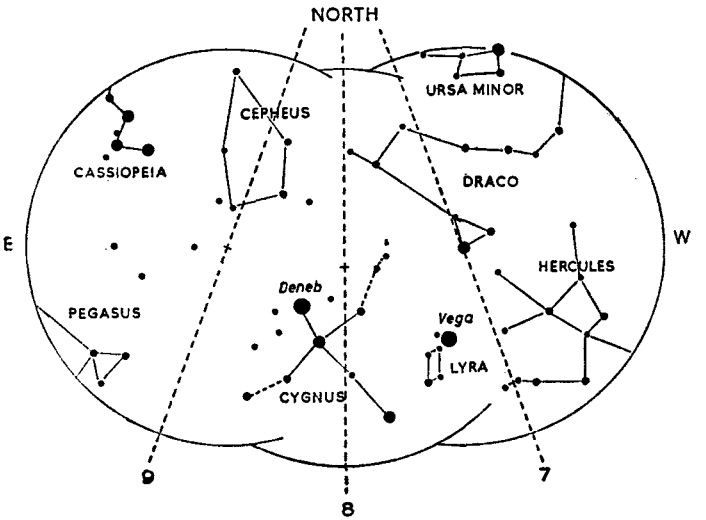


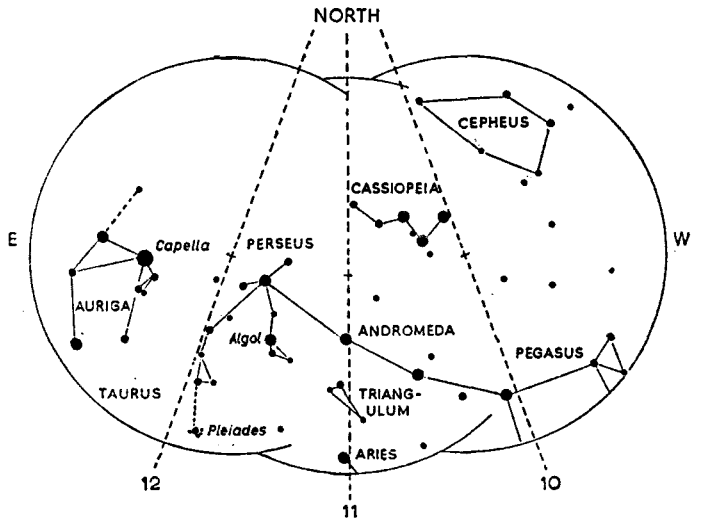
October 6 at 3h	October 21 at 2h	**12R**
November 6 at 1h	November 21 at midnight	
December 6 at 23h	December 21 at 22h	
January 6 at 21h	January 21 at 20h	
February 6 at 19h	February 21 at 18h	





Overhead stars





Overhead stars

Events in 1975

ECLIPSES

In 1975 there will be four eclipses, two of the Sun and two of the Moon.

11 May – a partial eclipse of the Sun, visible in West Africa and Europe.

25 May – a total eclipse of the Moon, visible in Europe, Africa, and America.

3 November – a partial eclipse of the Sun, visible in Antarctica.

18 November – a total eclipse of the Moon, visible in Asia, Europe, Africa and America.

THE PLANETS

Mercury will be seen most easily as an evening star at greatest eastern elongation on 23 January and 17 May, and as a morning star at western elongation on 25 October.

Venus will be a brilliant object in the spring months as an evening star. Greatest eastern elongation is on 18 June, and greatest elongation west on 7 November.

Mars will be a morning star for most of the year, coming to opposition in Taurus on 15 December.

Jupiter is in conjunction on 22 March, and will be at opposition in Pisces on 13 October.

Saturn is at opposition on 6 January in Gemini, and in conjunction on 15 July.

Uranus is at opposition in Virgo on 21 April.

Neptune is at opposition on 1 June in Scorpius.

Pluto is at opposition on 29 March.

The Planets in 1975

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	300°	259°	345°	105°	212°	251°
	21	319	269	348	104	213	251
February	6	339	281	351	103	213	252
	21	358	292	354	102	213	252
March	6	13	302	357	102	212	252
	21	31	314	1	102	212	252
April	6	50	326	5	102	211	252
	21	68	338	8	103	211	252
May	6	86	349	12	104	210	251
	21	103	0	15	106	209	251
June	6	120	12	18	108	209	251
	21	135	23	21	109	209	250
July	6	148	34	23	111	209	250
	21	157	44	24	113	209	250
August	6	160	55	25	115	209	249
	21	154	64	25	117	209	249
September	6	145	73	25	119	210	249
	21	143	80	23	120	211	250
October	6	150	87	21	122	212	250
	21	161	91	19	122	213	250
November	6	177	93	17	123	214	251
	21	193	91	16	123	215	251
December	6	210	87	15	123	215	252
	21	227	81	16	122	216	252
Conjunction:							
Inferior		Aug. 27	—	—	—	—	—
Superior		—	—	Mar. 22	July 15	Oct. 26	Dec. 4
Opposition:		—	Dec. 15	Oct. 13	Jan. 6	Apr. 21	June 1

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which the planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *Where may Saturn be found at midnight on March 21?*
The table opposite shows the longitude of Saturn on this date to be 102°. Star chart 4R shows the stars at midnight at the end of March, and contains the ecliptic from about longitude 100°. It is then seen that Saturn will be well up in the west in the centre of the figure of Gemini.

(2) *What is the bright planet rising in the north-east at about 22 h. at the end of September?*
The second diagram of star chart 9R shows the stars in the north-east at this time, and it is clear that a planet just above the horizon at this time will have a longitude of about 80°. The table opposite shows that the only possible planet is Mars.

The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about 23½ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before

sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the following pages.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and elongations, always follows the same order, but the intervals between them are not equal. Thus, if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

		Mercury	*Venus*
Inferior conj.	to Elongation West	22 days	72 days
Elongation West	to Superior conj.	36 days	220 days
Superior conj.	to Elongation East	36 days	220 days
Elongation East	to Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general, it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most noticeable

with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1971), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance from Earth and Sun. The rings are now beginning to close again, but are still widely open, and the planet is a brilliant object when at opposition.

Uranus, *Neptune* and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the March, April and June notes.

Phases of the Moon, 1975

New Moon	d	h	m	*First Quarter*	d	h	m	*Full Moon*	d	h	m	*Last Quarter*	d	h	m
												Jan.	4	19	04
Jan.	12	10	20	Jan.	20	15	14	Jan.	27	15	09	Feb.	3	06	23
Feb.	11	05	17	Feb.	19	07	39	Feb.	26	01	15	Mar.	4	20	20
Mar.	12	23	47	Mar.	20	20	05	Mar.	27	10	36	Apr.	3	12	25
Apr.	11	16	39	Apr.	19	04	41	Apr.	25	19	55	May	3	05	44
May	11	07	05	May	18	10	29	May	25	05	51	June	1	23	23
June	9	18	49	June	16	14	58	June	23	16	54	July	1	16	37
July	9	04	10	July	15	19	47	July	23	05	28	July	31	08	48
Aug.	7	11	57	Aug.	14	02	24	Aug.	21	19	48	Aug.	29	23	20
Sept.	5	19	19	Sept.	12	11	59	Sept.	20	11	50	Sept.	28	11	46
Oct.	5	03	23	Oct.	12	01	15	Oct.	20	05	06	Oct.	27	22	07
Nov.	3	13	05	Nov.	10	18	21	Nov.	18	22	28	Nov.	26	06	52
Dec.	3	00	50	Dec.	10	14	39	Dec.	18	14	40	Dec.	25	14	52

All times are G.M.T.

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MONTHLY NOTES, 1975

January

New Moon: 12 January *Full Moon:* 27 January

Earth is at perihelion (nearest to the Sun) on 2 January, when its distance from the Sun is about 91,400,000 miles (147,100,000 km).

Mercury is at greatest eastern elongation (19°) on 23 January, and for a few days at this time there will be a chance to see the planet as an evening star, low in the south-west at about 17 ^{h}. Mercury will be brighter before the date of greatest elongation.

Venus will be a brilliant object in the evening sky throughout the spring and early summer months this year, reaching its greatest eastern elongation in June (see page 78). In January the planet is well south of the equator and at the beginning of the month it sets in the south-west shortly after the Sun. By the end of the month it should be visible for about two hours after sunset. Magnitude −3·4.

Mars is a morning star, rising in the south-east about two hours before the Sun. It will be found in the small part of Ophiuchus that lies between Scorpius and Sagittarius, but it moves into the latter constellation in mid-January. Mars is not very conspicuous (magnitude +1·7 to +1·6) and will not begin to make a more brilliant appearance until the summer months.

Jupiter is in the south at sunset and sets in the west in mid-evening. It will be seen moving direct in Aquarius below the right-hand side of the Great Square of Pegasus (see diagram in the June notes, p. 79). The planet was at opposition in September last, and is now fading as its distance increases (magnitude −1·8 to −1·7).

Saturn is at opposition on 6 January, when it may be seen high in the south at midnight among the stars of Gemini (see diagram, page 61). The planet is much brighter (magnitude −0·2) than any of the surrounding stars, but is not quite as bright as it was at the last opposition in December 1973. Its distance from the earth is about the same at 748 million miles (1,200 million km), but the rings, which were wide open in 1973, are now beginning to close and it is this fact that causes the decrease in brightness. A small telescope will show the largest satellite, Titan, which may be seen to the west of the planet on the night of opposition, and may then be followed through its sixteen-day revolution about Saturn.

TITAN – THE SATELLITE WITH ATMOSPHERE

Saturn is still splendidly placed for observation from Britain and the United States; it remains in Gemini, at almost its maximum distance north of the celestial equator. The rings, too, are quite open, though not to the extent that they were in 1974.

The Jupiter probe Pioneer 11, scheduled to by-pass Jupiter in December 1974, will then be put into a 'Saturn encounter' path; but this encounter will take place a mere six months before that of the 1977 Mariner to Jupiter and Saturn, which is not yet anything like ready for launching.

Saturn, with its belts and rings, is a fascinating planet as well as a magnificent one; but nowadays astronomers are paying almost as much attention to Titan, the senior member of the satellite family. It has long been known to have an atmosphere; Kuiper first established this in 1944, when he detected a mantle of methane. Some notes about Titan were given in the 1974 *Yearbook*. Since then, however, there have been interesting developments. Hydrogen as well as methane has been found in Titan's

atmosphere, and the surface pressure is, in all, 100 millibars – ten times greater than that on the surface of Mars.

Yet Titan is smaller than Mars. Its diameter is not known with precision; estimates range from 3,500 miles down to only 2,700 miles, but at any rate there is every reason to suppose that Titan is at least as large as the planet Mercury, though less massive. (Mars, of course, has a diameter of slightly over 4,200 miles.) Why should Titan have a relatively thick atmosphere? According to current theory, the explanation is rather involved. Light gases, such as hydrogen, can – and do – escape from Titan; but they cannot escape from the strong gravitational field of Saturn itself, and so they remain in orbit round Saturn. The overall effect is that of a ring of particles, with Titan in the midst of them. As Titan moves along, it sweeps up the light gases once more, so that we have a kind of swings-and-roundabouts situation; the atmosphere which is lost is compensated for by the amount collected, and the basic density remains the same. It has been calculated that it takes about six years for a complete cycle of the atmosphere of Titan. During that period the satellite has been round Saturn many times; the revolution takes a mere 15 days 22¾ hours.

Any small telescope will show Titan; the stellar magnitude is just below 8. In colour the satellite is orange or red, though the light intensity is so low that few visual observers will call it anything but slightly 'off-white'. A further point of interest concerns the effect of solar ultra-violet radiation upon a primitive type of atmosphere such as that of Titan. Laboratory experiments have shown that hydrocarbons and amino acids can be built up, and this leads on to a link with what we may call 'life' – though it would be a bold man indeed who would claim that any form of life is likely upon chilly Titan at the present moment!

According to present plans, the Mariner vehicle to be sent up in 1977 will actually by-pass Titan before starting its research programme with regard to Saturn itself. The encounter is due in 1981, so that by then we ought to have more positive information about Titan – the only satellite in the Solar System known to have a comparatively dense atmosphere.

Mira Ceti, the 'Wonderful Star'

The first known variable star, Mira, is well on view this month. It was seen in 1596 by the Dutch astronomer Fabricius; later it was recorded by Johann Bayer, who gave it the Greek letter Omicron in the constellation of Cetus, the Whale; and in 1625 Phocylides Holwarda established that it appears periodically to the naked eye. Its period is approximately 331 days, though, as with all stars of its type, neither the period nor the amplitude is perfectly regular.

At its best, Mira can exceed the second magnitude; the brightest maximum of recent years was that of 1969, when the star rose to magnitude 2·3. At other times, however, the maximum magnitude may be as low as $3\frac{1}{2}$, or occasionally, even 4. Generally speaking Mira is prominent for only a few weeks every year, from the point of view of the naked-eye observer. It is too early as yet to say what will happen this January; but at the very least Mira ought to be identified without difficulty when the Moon is out of the sky. Like almost all long-period stars Mira is strongly red, but optical aid is needed to bring out the colour well. At minimum, the magnitude sinks to 9.

The Crowded Zodiac!

It is usually said that there are twelve constellations of the Zodiac, in which the Sun, the Moon, and the bright planets are always to be found. In fact, the large constellation of Ophiuchus, the Serpent-bearer, intrudes into the Zodiac between Scorpius and Sagittarius; and Mars lies here at the start of 1975. At present Mars is a long way away, and is much fainter than Antares, the leader of Scorpius. Unwary observers have often been known to mistake Mars for a nova when it is distant and comparatively inconspicuous – particularly when, as now, it is outside the band of constellations which is conventionally termed the Zodiac.

February

New Moon: 11 February *Full Moon:* 26 February

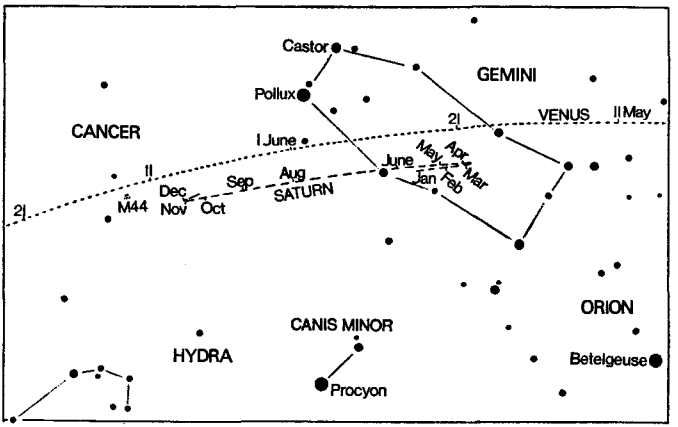
Mercury is in inferior conjunction on 8 February, and will not be visible during the month.

Venus is an evening star, setting more than two hours after the Sun in the western sky. The planet moves rapidly north, crossing the equator at the end of the month, so that it is then well north of the Sun. A noteworthy event this month is the close conjunction of Venus and Jupiter on 17 February. At 19^h on that day, Venus will pass about a fifth of a degree south of Jupiter, and this unusually close approach should be well worth observing. Both planets are very bright (magnitudes: Venus $-3{\cdot}4$, Jupiter $-1{\cdot}6$) and both are moving direct, but the rapid motion of Venus will be very obvious if the pair can be observed for a few days before and after this conjunction.

Mars is a morning star rising in the south-east more than an hour before the Sun. It is now moving direct among the stars of Sagittarius, and although it will remain well south of the equator until the end of May, it grows slowly brighter (magnitude $+1{\cdot}6$ to $+1{\cdot}5$).

Jupiter is now moving rapidly towards conjunction with the Sun. At the beginning of February it sets in the west more than three hours after the sun, but by the end of the month this interval is reduced to one hour. The planet passes from Aquarius into Pisces in mid-February, when its magnitude is $-1{\cdot}6$. The very close conjunction of Jupiter with Venus is mentioned in the notes above.

Saturn continues to move retrograde among the stars of Gemini, but loses a little of its brightness during the month (magnitude −0·1 to +0·1). It is still visible for most of the night, but sets before dawn to the north of west.



Saturn, 1975

EPSILON AURIGÆ: BLACK HOLE OR YOUNG STAR?

The brilliant yellow star Capella is almost overhead during winter evenings as seen from Britain and the northern United States. Its brightness means that it cannot be overlooked; it is an extremely close binary, and has a G-type spectrum, so that the surface temperature is similar to that of the Sun even though Capella is much more luminous. Close beside it are three fainter stars making up a triangle; they used to be nicknamed the Hædi, or Kids. One of them (Eta Aurigæ) is entirely unremarkable. The faintest member of the trio, Zeta Aurigæ – still occasionally referred to by its old proper name of Sadatoni – is a particularly interesting eclipsing binary with the very long period of 972 days. The star at the apex of the triangle, Epsilon Aurigæ, may be more remarkable still, and even now we are not certain of its true nature.

As long ago as 1821 Fritsch discovered that it is variable; normally it shines not far below the third magnitude, but at

minimum it fades to below the fourth. Originally it was thought to be irregular, but it was then found to be an eclipsing binary with a period of 27½ years – easily a record. The next minimum is not due until the 1980s, and for most of the time Epsilon Aurigæ seems to shine steadily in light.

The primary is a very luminous supergiant, some 60,000 times more powerful than the Sun and with 35 times the solar mass – so that by stellar standards it is a true heavyweight. The spectral class is F2. Because it is so luminous and yet by no means conspicuous, it is clearly very remote; the distance is estimated as 3,400 light-years. The secondary in the Epsilon Aurigæ system has never been seen directly, and radiates only in the infra-red. Yet its mass is 23 times that of the Sun, and a normal star of this mass ought to be nearly half as bright as the primary. Evidently there is something strange about it.

For many years it was assumed that the secondary must be a very young star, still contracting toward the Main Sequence. From the duration of the eclipses it causes, the size can be worked out; and on this interpretation the invisible secondary must be so big that it could swallow up the orbits of all the planets in the Solar System out to and beyond Saturn, making it the largest individual star known. However, another theory has been widely supported of late; it was originally proposed by A. G. W. Cameron in the United States, who maintained that the secondary was nothing more nor less than a Black Hole.

Black Holes have caused a great deal of discussion, though it must be stressed that we have as yet no hard and fast proof that they exist. Of the various candidates, Epsilon Aurigæ – or, rather, the secondary – comes high in the list. If the initially very massive star has evolved off the Main Sequence and has become a collapsar, it may be assumed that the infra-red radiation which we pick up comes from the dust which is spiralling inward towards eventual capture in the Black Hole, and is being heated by radiation from the primary.

It is still too early to decide between these rival theories – and, of course, both may be wrong; but at least we may be sure that

Epsilon Aurigæ is a most unusual object, normal though it looks when observed through an ordinary telescope.

Occultations of Planets by Planets

This month's close conjunction of Venus and Jupiter will be well worth watching, even though it is not scientifically important. (Photographic enthusiasts will certainly wish to record it.) There have, of course, been many conjunctions between planets over the years; one which caused interest among amateurs took place in May 1955, when Jupiter and Uranus were in the same telescopic field. It was informative to compare Uranus with the Jovian satellites; the planet was obviously larger but with a lower surface brightness, so that direct magnitude comparisons were not easy.

Mutual planetary occultations are extremely rare, and no observer alive today will have seen one! The first on record was that of 3 October 1590, when an occultation of Mars by Venus was watched by Michael Möstlin, Professor of Mathematics at Heidelberg. On 17 May 1737, Mercury was occulted by Venus. There was a 'near miss' on 21 July 1859, when Venus and Jupiter were so close together that to the unaided eye they were not separable.

It is not really surprising that these phenomena are so uncommon when we remember the small apparent sizes of the planets and the relative slowness of their movements in the sky. Even occultations by the Moon are less frequent than the casual observer might think, though of course many do occur each year.

Sirius

Evenings in February are favourable for looking at Sirius, which is by far the most brilliant star in the sky. It seems to twinkle violently as seen from Britain and the northern United States, and to flash various colours even though it is in fact pure white. Twinkling or scintillation is due entirely to the Earth's atmosphere; Sirius shows it very strongly because of its extreme brightness and because of its low altitude. When seen from more southerly countries, where it appears higher up in the sky, it twinkles less, though the scintillations are always very obvious.

March

Summer Time in Great Britain and Northern Ireland commences on 16 March.

New Moon: 12 March *Full Moon:* 27 March

Equinox: 21 March

Mercury is at greatest western elongation (27°) on 6 March, but will then be very low in the dawn sky and is not likely to be seen.

Venus sets later each evening to the north of west. By the end of the month it will be visible for three hours after sunset, and although it is still of the same magnitude (−3·4), it may be seen in the late evening as a brilliant object in a dark sky.

Mars continues to rise rather more than an hour before the Sun. It is growing brighter (magnitude +1·5 to +1·3) and moves through Capricornus during March.

Jupiter is in conjunction with the Sun on 22 March, and will not be visible during the month.

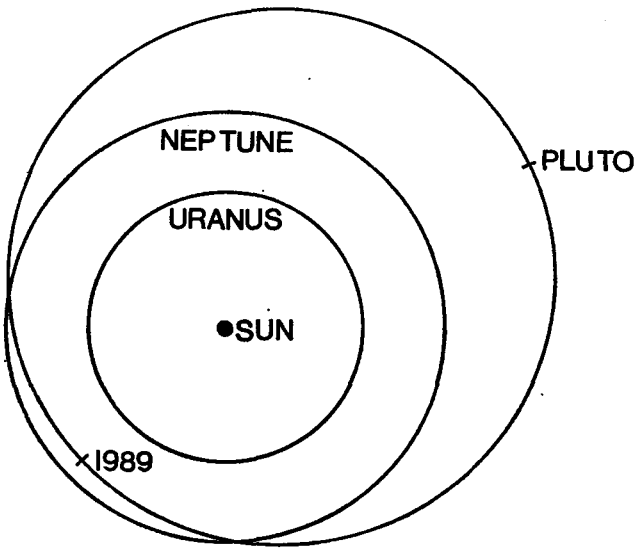
Saturn is an evening star, but now sets in the early morning hours. It reaches a stationary point on 14 March in the centre of the figure of Gemini (see diagram on page 61) and after this date it begins once again to move direct. The planet continues to fade (magnitude +0·1 to +0·2), but is easily recognized since it is brighter than any of the surrounding stars.

Pluto is at opposition on 29 March on the borders of Virgo and

Coma Berenices, but is too faint to be seen with small instruments (magnitude +15). The very eccentric orbit of this planet causes it to come nearer to the Earth at each opposition, and in 1975 the distance is 2,772 million miles (4,462 million km).

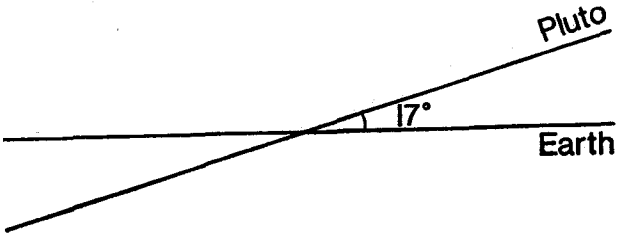
PLUTO AT OPPOSITION

This month Pluto, generally the outermost planet of the Solar System, comes to opposition – but the event will hardly be of interest to the amateur observer, because even at its best Pluto is very faint; it cannot be seen without a telescope of considerable aperture. Its revolution period is 247·7 years, so that it has not completed very much of its orbit since its discovery by Clyde Tombaugh, at the Lowell Observatory, in 1930. The next perihelion passage is due in 1989, and for some years to either side of that date Pluto will be closer-in than Neptune; even so, it will never come within the range of small instruments.



A diagram of the orbits of the outermost planets, as shown here, might lead to the idea of a possible collision between Pluto

and Neptune, since their paths appear to cross. In fact this is out of the question at the present time, because the orbit of Pluto is not only exceptionally eccentric, by planetary standards, but is also inclined at the relatively sharp angle of 17 degrees, as shown in the second diagram – so that Pluto and Neptune do not approach each other at all closely.



Pluto has set astronomers puzzle after puzzle since it was identified. Lowell, who first worked out its position, failed to locate it because it was considerably fainter than he had expected; and if it is really as small as the measurements indicate, it could not cause detectable perturbations in the movements of giants such as Neptune and Uranus. Yet it was by these very perturbations that it was tracked down. Was Lowell's prediction purely fortuitous? This does not seem plausible; but it is even less likely that Pluto is exceptionally dense. There may well be another planet awaiting discovery, but if so it will be very dim and difficult to identify.

According to one hypothesis, Pluto is nothing more nor less than a former satellite of Neptune which broke free and moved away in an independent orbit. Support comes from the fact that Triton, Neptune's remaining large satellite, is comparable in size with Pluto, and is the only large satellite in the Solar System to have retrograde motion. (Because the planet Uranus has an axial tilt of 98 degrees, its satellites are technically retrograde; but they revolve in the same sense as Uranus itself, whereas Triton, relative to Neptune, does not.) It has been suggested that the event which freed Pluto threw Triton into a retrograde orbit. Whether this is true or not remains to be seen.

The best method of determining Pluto's diameter with real accuracy would be to observe an occultation of a star by the planet. G. E. Taylor has had great success with this method for Io, the innermost of Jupiter's Galilean satellites, and also with Neptune. Unfortunately occultations by Pluto are excessively rare, and we must wait for Nature to provide us with an opportunity. At its next aphelion, in the year 2014, Pluto will be over 4,500 million miles from the Sun, and will be excessively faint; it will also, incidentally, be far south in the sky.

The Celestial Lynx

Constellations vary enormously in size and importance. Some, such as Orion and Ursa Major, can be identified at a glance because of their obvious patterns and their bright stars; others are so dim that they hardly seem to merit a separate identity. The far south of the sky abounds with very small, obscure constellations – which is understandable, since these regions were unobservable by the ancient observers who formed the constellations which we know, and later astronomers were only too anxious to secure lasting recognition by adding new groups to the sky-map!

Even in the northern hemisphere there are some very faint, barren groups; and one of these is Lynx, which was formed by the Gdańsk astronomer Hevelius in the seventeenth century. It lies between the Pointers (Dubhe and Merak) on the one side, and Capella and the Twins on the other; it has of course no mythological associations, and neither has it any star as bright as the third magnitude. Most of it is circumpolar from Britain. There is no definite pattern, and not even the most vivid imagination can make a lynx or any other animal out of it. From time to time there have been suggestions about revising the entire sky-map, but our present-day constellations have become so firmly established that it would be pointless to try to alter them now.

April

New Moon: 11 April *Full Moon:* 25 April

Mercury is in superior conjunction on 18 April, and will not be visible during the month.

Venus is now well north of the equator and sets north of west in the late evening. The planet is growing a little brighter (magnitude −3·5 to −3·6) and towards the end of the month it will be seen among the stars of Taurus, passing 7 degrees north of Aldebaran on the evening of 22 April.

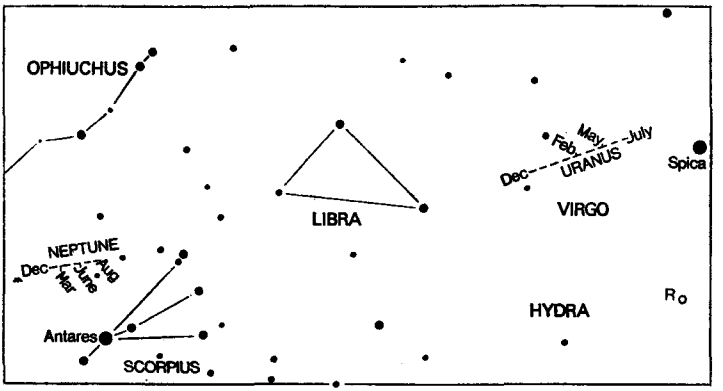
Mars continues to rise about an hour before sunrise, and grows brighter (magnitude +1·2 to +1·1). It is still well south of the Sun, but is moving north, passing into Aquarius at the beginning of April, and moving across this constellation during the month.

Jupiter now begins to appear as a morning star, but rises in the east less than an hour before the Sun at the end of the month. It may perhaps be seen among the stars of Pisces, below the left-hand side of the Great Square of Pegasus.

Saturn is an evening star, setting to the north of west an hour or so after midnight. As the figure of Gemini sets in an upright position, Saturn will be seen below the Twins, Castor and Pollux (magnitudes: Saturn +0·3, Castor +1·6, Pollux +1·2).

Uranus is at opposition on 21 April in Virgo, some degrees to the east of Spica, and its magnitude at this time is +5·7, so that it should just be visible to the naked eye. In a small telescope it

appears as a greenish disk. The distance of Uranus at opposition is about 1,620 million miles (2,610 million km).



Uranus and Neptune, 1975

PROBE TO URANUS?

Uranus, the third of the giant planets, comes to opposition this month, and it is easy enough to find; keen-sighted people can see it without optical aid when the sky is dark and clear. It was the subject of an article by G. E. Satterthwaite in the 1974 *Yearbook*. It is an interesting world; its make-up differs from that of Jupiter or Saturn, and there is, of course, the extraordinary tilt of the axis, which amounts to 98 degrees. This leads to very strange 'seasonal' effects on the planet!

Now that the first Pioneer has made a successful pass of Jupiter, and hard and fast plans have been made for the Jupiter-Saturn Mariner due to be launched in 1977, astronomers and space researchers are starting to think very seriously about a probe to Uranus. This was one of the objectives of the ill-fated Grand Tour project, which the Americans cancelled on financial grounds; but reaching Uranus, by using the 'slingshot' technique involving the gravitational field of Jupiter, is by no means impossible. Moreover, it is thought that present-day techniques would allow for maintaining contact with a probe encountering Uranus,

though as yet the same could hardly be said for the much more remote Neptune.

Uranus shows very little surface detail – and none at all with small telescopes. However, it is always worth locating, and any pair of binoculars will be good enough to identify it. All the five satellites are considerably smaller than our Moon, and it is unlikely that any of them can retain atmosphere.

Chi Cygni

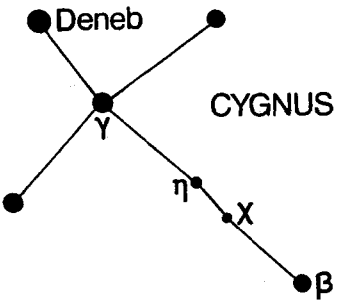
During April Cygnus, the Swan, is best seen in the hours before dawn, though part of it is always circumpolar from Britain. It is a large and imposing constellation, containing one star of the first magnitude (Deneb) and several more of the second and third; it is crossed by the Milky Way, and there are many rich star-fields.

Cygnus is also rich in variable stars. Of these, one of the most interesting is Chi Cygni, which should be easily visible with the naked eye this month. Its variability was discovered by Kirch as long ago as 1686, and it belongs to the Mira class; the period amounts to 407 days, though of course this is subject to fluctuation either way.

What makes Chi Cygni notable is its tremendous magnitude range. It can attain magnitude 3, but at minimum it sinks to below 14, so that it disappears altogether as seen through small telescopes. In fact Chi Cygni is the holder of the 'range record' – and it is also very powerful in the infra-red. If our eyes were sensitive to this wavelength range, Chi Cygni would appear as one of the very brightest objects in the entire sky.

It is easy to locate, because it lies in the pattern of the 'Cross of Cygnus' between the centre star (Gamma) and the lovely coloured double Beta or Albireo. Close beside Chi is the normal fourth-magnitude star Eta Cygni, which makes an excellent comparison when the variable is bright. The chart given here will be of help to the binocular-user who wants to carry out observations this spring.

It is useful to note the maximum magnitude. In his books



J. S. Glasby, former Director of the Variable Star Section of the British Astronomical Association, states that the star can reach magnitude 2·3, but certainly most maxima are much below this, and there are some years in which the star remains a very faint object as seen with the naked eye. When observed with a telescope, or with binoculars when the star is near maximum, the red colour is very obvious indeed.

By the summer Chi Cygni will have dropped below naked-eye visibility, and by the autumn it will be approaching minimum, so that it cannot then be identified except with a powerful telescope and an adequate set of detailed charts.

Another long-period variable is also well seen this month, but in the evening sky. This is R Leonis, near Regulus. The period is much shorter than that of Chi Cygni (312 days) and the average range is between magnitudes $5\frac{1}{2}$ and $10\frac{1}{2}$ – a mere five magnitudes, as against more than ten magnitudes for Chi Cygni. R Leonis is always visible in a small telescope, and when at its best can be seen with the naked eye; the magnitude has been known to reach $4\frac{1}{2}$. This year, however, maximum occurs in the summer, when the star is too near the Sun to be observable.

THE 'SOLITARY ONE'

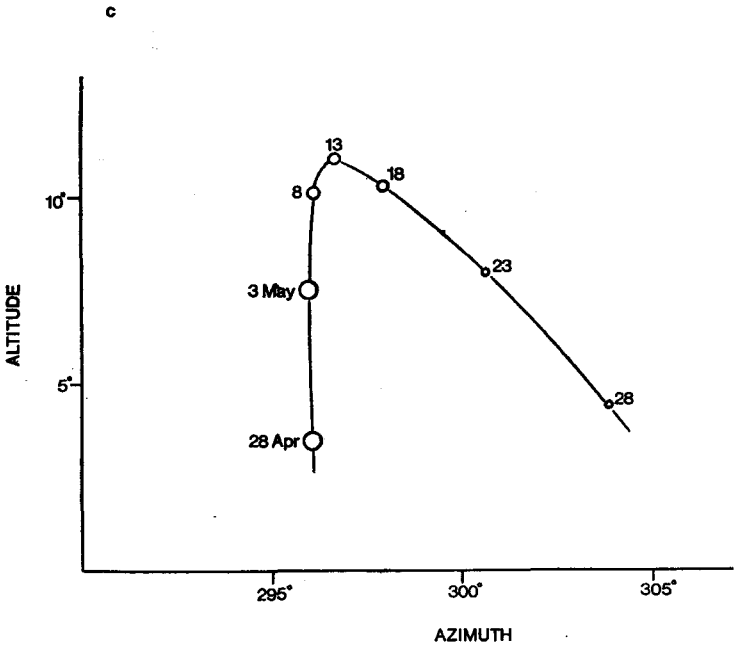
Rather low in the southern sky during spring evenings may be seen a second-magnitude star of a distinctly red colour. This is Alpha Hydræ, the only bright star in the huge, sprawling constellation of Hydra, the Watersnake. Its proper name is Alphard;

it is called 'the Solitary One' because it lies in an exceptionally barren part of the sky. It has a K-type spectrum, and is 94 light-years from us. To locate it, simply follow the direction indicated by a line from Castor through Pollux. When observed through binoculars or a telescope, the redness of Alphard is very marked.

May

New Moon: 11 May *Full Moon:* 25 May

Mercury is at greatest eastern elongation (22°) on 17 May, and this is a favourable opportunity to see this planet as an evening star after sunset. The diagram below shows the changes in altitude and azimuth (true bearing from the north through east, south and west) of Mercury on successive evenings when the Sun is six degrees below the horizon; this will be about 45 minutes after



Mercury, May 1975

sunset at this time of year. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest before the date of greatest elongation.

Venus is a splendid object in the evening sky, setting more than three hours after the Sun, so that it is visible until nearly midnight. In mid-May it reaches its highest northern declination (nearly 26°) and may then be seen among the stars of Gemini. Venus passes three degrees north of Saturn on the evening of 24 May, and four degrees south of Pollux on 31 May. Its rapid motion at this time is shown on the diagram on page 61.

Mars continues its slow emergence as a morning star, rising about two hours before the Sun at the end of the month. It grows a little brighter (magnitude +1·1 to +1·0) and passes from Aquarius into Pisces in mid-May. By the end of the month it will be north of the equator and then begins to make a more impressive appearance.

Jupiter is now beginning to be seen more easily in the morning sky in the east. It rises about two hours before the Sun at the end of May, and may be seen in the constellation Pisces, south of the left-hand side of the Great Square of Pegasus.

Saturn is an evening star, setting at midnight in early May. On the evening of 23 May, the planets Venus and Saturn will be seen close together in the western sky. The closest approach, with Venus three degrees north of Saturn, will not take place until the planets have set. Although the sky is never really dark at this time of year, it should be possible to find Saturn to the south of the brilliant Venus (magnitudes: Venus −3·8, Saturn +0·4).

A partial eclipse of the Sun on 11 May is visible in Europe in the early morning. About 60 per cent of the Sun will be obscured by the Moon as seen from the British Isles. See notes on page 110.

A total eclipse of the Moon on 25 May will be visible generally in

North and South America, totality lasting from $5^h\ 03^m$ to $6^h\ 33^m$ G.M.T. See notes on page 110.

SOLAR AND LUNAR ECLIPSES UNTIL 1980

The partial solar eclipse of 11 May reaches its maximum phase (83%) in the Arctic; the eclipse is not total anywhere. The total lunar eclipse of 25 May is visible from America, but not from Europe. Any particular point on the Earth's surface will see more lunar than solar eclipses over a given period – because an eclipse of the Moon is visible over a complete hemisphere of the Earth, whereas an eclipse of the Sun is confined to a relatively narrow band. (The zone of totality for a solar eclipse can never be more than 169 miles wide, and is generally much less.)

It may be useful to give a list of eclipses for the period from 1975 to 1980:

Eclipses of the Sun

Total: 23 October 1976 (Kenya to South Pacific), 12 October 1977 (South American area), 26 February 1979 (North American area), 16 February 1980 (Atlantic to China).

Partial: 11 May 1975 (see Notes), 3 November 1975 (very nearly total in the Arctic), 7 April 1978 (Antarctic, 79%), 2 October 1978 (69%, Arctic).

Annular: 29 April 1976 (Africa to China), 18 April 1977 (Africa), 22 August 1979 (Pacific to Antarctic), 10 August 1980 (South America).

Eclipses of the Moon

Total: 18 November 1975 (see Notes), 24 March 1978 (not visible in Britain or the U.S.A.), 16 September 1978 (partly visible in Britain, not in the U.S.A.), 6 September 1979 (partly visible in the U.S.A., not in Britain).

Partial: 13 May 1976 (10%; partly visible in Britain, not in the U.S.A.), 4 April 1977 (20%; visible in the U.S.A., partly visible in Britain) and 13 March 1979 (90%; visible from Britain but not from the U.S.A.).

Cratered Mercury

There is a legend that the great astronomer Copernicus, author of the book which sparked off the 'scientific revolution', never managed to see the planet Mercury because of river-mists rising from near his home. The story is almost certainly untrue; but Mercury is indeed the least prominent of the naked-eye planets (unless we include Uranus, which is on the fringe of naked-eye visibility). Mercury is never visible against a dark background, and is best observed telescopically when both it and the Sun are high, though this naturally needs a powerful instrument – preferably a refractor – equipped with accurate setting circles. (Sweeping around during the daytime in an effort to find Mercury is foolhardy in the extreme; sooner or later the Sun will enter the telescopic field by mistake, with disastrous results.)

In the pre-probe era the best map of Mercury was that drawn more than forty years ago by E. M. Antoniadi, using the 33-inch refractor at Meudon, near Paris. He published a short book about it – though, strangely, no English translation appeared until 1974! [E. M. Antoniadi: *The Planet Mercury*, Keith Reid Ltd, 1974.] Antoniadi mapped the surface features as accurately as he could, and gave them names; he believed that the rotation period was the same as the revolution period round the Sun – 88 Earth-days in each case – and although it is now known that the true rotation period is only 58½ days, Antoniadi's actual observations were correct so far as they went. Yet the Mercurian surface markings are hard to see from Earth, and it was only in 1974 that radar work established the existence of craters there. Since structures of the same basic type have also been found on Venus and Mars, craters appear to be the rule rather than the exception in the inner part of the Solar System.

It is absolutely impossible to see the Mercurian craters directly with our Earth-based telescopes; for that matter even the huge Martian structures cannot be identified for what they really are – and with Venus, of course, nothing whatsoever can be seen apart from the top part of the dense, cloud-laden atmosphere.

So far as Mercury is concerned there is one line of research

open to the well-equipped amateur. With Venus, the predicted and the observed phase do not always agree; at evening elongations, when Venus is waning, half-phase or dichotomy is always ahead of prediction, whereas during morning elongations, when Venus is waxing, dichotomy is late. It has never been established whether this 'Schröter effect' also applies to Mercury; opinions differ. Of course, the effect is purely optical, but it is by no means devoid of interest.

R Coronæ

During May evenings the orange star Arcturus is very prominent. Not far from it is the semi-circle of stars marking Corona Borealis, the Northern Crown – one of the very few groups bearing some resemblance to the object after which it is named. Inside the 'bowl' of the Crown is R Coronæ, one of the most famous variable stars in the sky. Normally it is of about the sixth magnitude, and easy to see with any optical aid; but at unpredictable intervals it falls abruptly to minimum, and may descend to below the twelfth magnitude. It is the prototype of a very small class of variable stars, and is the brightest of its type. It is a favourite object for amateur study, even though it may remain almost steady for months or even years at a time.

At the start of 1974, R Coronæ was passing through minimum, and was below binocular range, though by the summer it had regained its normal brightness. Whether it will be bright or faint during the spring of 1975 remains to be seen.

June

New Moon: 9 June *Full Moon:* 23 June

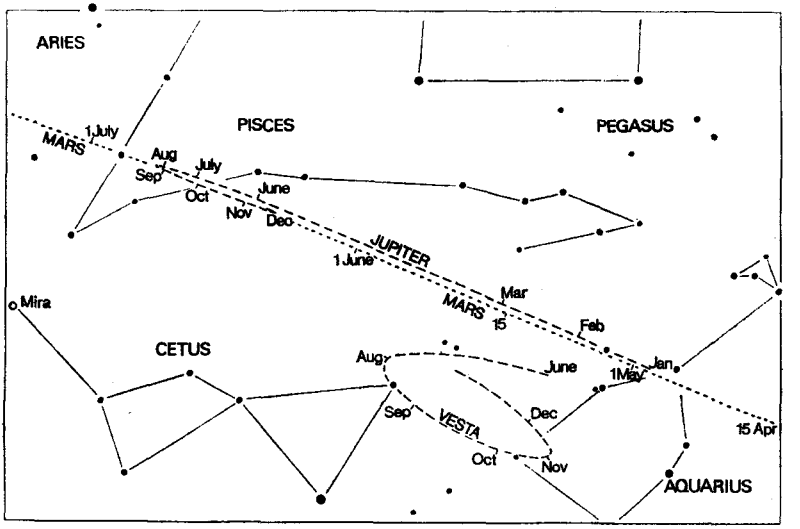
Solstice: 22 June

Mercury is in inferior conjunction on 10 June and will remain too close to the Sun to be seen during June.

Venus is at greatest eastern elongation (45°) on 18 June. In a small telescope it then appears to be half illuminated, like the Moon at First Quarter. It sets a little earlier each evening, but is still a splendid object (magnitude −3·8 to −4·0) in the evening sky until about 22^h.

Mars is a bright morning star, rising in the east in the early morning hours (magnitude +1·0 to +0·8). It is moving direct in the constellation Pisces, and is quite easy to distinguish from the fainter stars around it. It will be seen to be moving rapidly towards the planet Jupiter, and on the evening of 15 June it will be very close to that planet. The nearest approach actually occurs at 6^h on the 16th, when Mars will be only half a degree south of Jupiter. Both planets are moving direct, but Mars more than four times as fast as Jupiter (see diagram on page 79).

Jupiter is also a morning star in Pisces, but it is much brighter than Mars, its magnitude increasing from −1·7 to −1·9 during the month. Jupiter rises shortly after midnight and is a brilliant object in a relatively barren part of the sky. The close conjunction with Mars on 15 June is described in the note above.



Jupiter and Mars

Saturn is now approaching conjunction but will be visible for an hour or so after sunset in the first half of the month, setting north of west in Gemini.

Neptune is at opposition on 1 June, but is not visible to the naked eye (magnitude +7·7). The planet is actually in the constellation Ophiuchus, some degrees to the north and east of Antares. Its position is shown on the diagram on page 69. The distance of Neptune from the Earth at opposition is about 2,720 million miles (4,380 million km), which may be compared with the distance of Pluto given in the March notes.

Heinrich D'Arrest and the Discovery of Neptune

Neptune is worthy of special note this month on two counts. First, the planet is at opposition; it is not far from Antares, and binoculars will show it, though admittedly it looks very like a star. Note also that it is now not much closer to us than Pluto; and as Pluto swings in toward its 1989 perihelion, there will be a period

during which Neptune will again become the outermost of the known members of the planetary system.

Secondly, 14 June is the centenary of the death of Heinrich Ludwig D'Arrest, who was one of the first men to identify Neptune. It is always said that the actual discoverers were the two mathematicians, Urbain Le Verrier in France and John Couch Adams in England, and that the optical identification was made by Johann Galle in Germany. This is correct so far as it goes; but mention should also be made of D'Arrest, who played a major part in the telescopic search.

D'Arrest was of French descent, as is evident from his surname; but he was born in Berlin and graduated at Berlin University, spending his life in Germany until he went to Denmark in 1857. In 1844 he discovered a periodical comet, which has been seen at most returns since then and now ranks as an 'old friend' even though it never becomes bright enough to be visible with the naked eye. In the same year he became assistant to the celebrated Encke in Berlin, and it was while he was here that the Neptune episode took place.

The story has been told so many times that there is no point in giving more than a very brief résumé of it here. Adams, in England, worked out the position of a new planet, from studying the perturbations which were exerted on Uranus – which had been discovered by Herschel in 1781, and which had been persistently straying from its calculated path. The Astronomer Royal, Airy, showed no great interest – until he heard about similar calculations made by Le Verrier, leading to almost exactly the same result. At Airy's request a search was started at Cambridge with the 12-inch refractor there, but the new planet was first identified at Berlin from Le Verrier's work.

Le Verrier had sent his results to Encke, and almost at once the search was begun. Galle and D'Arrest worked together; Galle at the telescope, and D'Arrest checking the stars against a detailed celestial map which was fortunately available. (Challis, working at Cambridge, did not have it.) In fact D'Arrest had heard Galle asking Encke's permission to undertake the task, and had asked

to be allowed to join in; Galle felt that 'it would have been unkind to refuse the wish of this zealous young astronomer'.

The hunt was started on 23 September 1846, with the 9-inch Fraunhofer refractor. First, Galle looked around for an object showing a small disk, but without result. It was D'Arrest who then suggested using the star map as a check; Galle was sceptical, but he showed his young assistant the cupboard where the star-maps were kept, and after rummaging through the drawer D'Arrest located the chart he wanted. Galle went back to the telescope, and called out the appearances and positions of the stars he could see. Then he described an object of about the eighth magnitude R.A. $22^h\ 53^m\ 25^s{\cdot}84$, and D'Arrest called out in excitement: 'That star is not on the map!' It was, of course, the planet: Neptune.

D'Arrest made haste to call Encke, and the three astronomers tracked the object until it set. Next night they saw it again, and saw that it had shifted in position; there could no longer be any doubt that the great discovery had been made. In recalling the story, then, one must not underestimate the part played by D'Arrest; had he not pressed for the use of the map, the discovery might have been delayed – in which case Challis, at Cambridge, might have found the planet first.

D'Arrest stayed at Berlin for another two years, and then, after a spell at Leipzig, he went to Copenhagen, where he stayed for the rest of his life. He discovered the asteroid Freia in 1862, as well as several comets; he measured the positions of various nebulæ, and also investigated the spectra of red stars. In fact he accomplished a great deal of useful work, but undoubtedly his main claim to fame rests upon his part in the discovery of Neptune.

Venus at Half-Phase

Venus is still brilliant; and on 18 June it reaches its greatest elongation from the Sun. It should then be approximately at dichotomy, or half-phase; but because of the so-called Schröter effect, it will probably reach dichotomy a few days earlier. Users of adequate telescopes will find it interesting to check the

phase each evening, and to see when dichotomy actually occurs.

ANTARES

During evenings in June the bright red star Antares is at its best as seen from Britain and the northern U.S.A. The name means 'the Rival of Mars', and certainly Antares is the reddest of the first-magnitude stars; its spectrum is of type M, and its diameter exceeds that of the Earth's orbit round the Sun. The faint companion looks distinctly greenish (mainly because of contrast) and is not a difficult telescopic object.

Antares is recognizable partly because of its brightness and colour, and partly because of the fact that it has a fainter star to either side of it – a characteristic shared by Altair in Aquila. Scorpius is a magnificent constellation, but from Britain it is never high up, and the 'sting' barely rises.

July

New Moon: 9 July *Full Moon:* 23 July

Earth is at aphelion (farthest from the Sun) on 6 July, when its distance will be 94,500,000 miles (152,100,000 km).

Mercury is at greatest western elongation (22°) on 4 July. It is then a morning star, but very low in the north-east and not very bright, so that it is likely to be lost in the bright dawn sky.

Venus reaches its greatest brilliancy as an evening star on 22 July, when its magnitude is −4·2. It is now moving rapidly towards conjunction with the Sun, and sets in mid-evening. The planet passes less than half a degree from Regulus on the night of 8 July, but this may be difficult to see in the twilight sky.

Mars is a morning star, but rises at midnight in mid-July. It grows still brighter (magnitude +0·8 to +0·6) and will be seen in Aries for the rest of the year. The path of the planet during this time is shown on the diagram on page 87.

Jupiter continues to grow brighter (magnitude −1·9 to −2·1) and rises in the east in Pisces at midnight at the beginning of July.

Saturn is conjunction with the Sun on 15 July, and will not be visible during the month.

THE PLANETS AT THEIR FURTHEST

Though it is summer in Britain and the United States, the Earth is at its greatest distance from the Sun early this month. The

seasons have very little to do with the Earth's orbital eccentricity; it is the tilt of the axis which matters. In fact, the orbit of the Earth does not depart greatly from the circular form, and the range is a mere three million miles between perihelion and aphelion. (With Mars, the eccentricity is greater, and shows up in the seasonal effects, particularly since there are no ocean areas. The southern hemisphere has a more extreme climate than the northern.)

Of the other planets, Venus and Neptune have orbits which are less eccentric than that of the Earth; the others are somewhat greater, with Pluto being much the most eccentric of all. This means that the distances of the planets show a wide range. It is interesting to note the greatest distances to which the various planets can recede: the following values are rounded off to the nearest million miles.

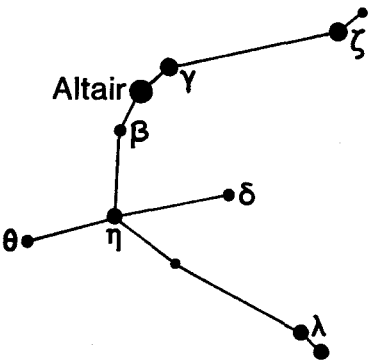
Planet	*Greatest distance from Earth: millions of miles*
Mercury	138
Venus	162
Mars	249
Jupiter	601
Saturn	1032
Uranus	1962
Neptune	2912
Pluto	4661

Venus is the planet which can approach the Earth most closely (within 24 million miles) – Mars is always ten million miles further away. When looking at a chart of the Solar System, it is sometimes difficult to appreciate the extent to which the outer parts are 'spread out'. For instance, it is tempting to regard Uranus and Neptune as near neighbours; but this is not true – they can never approach each other closer than about 900 million miles. In fact, Uranus is always much further away from Neptune than the

Earth's mean distance from Saturn. This explains why a probe to Uranus is now being seriously considered, whereas communications difficulties at the distance of Neptune can hardly be surmounted as yet.

ETA AQUILÆ

Aquila, the Eagle, is one of the most prominent of the northern constellations. Its leader, Altair, is one member of the unofficial 'Summer Triangle' (the others are Vega in Lyra and Deneb in Cygnus), and, like Antares, it is flanked by a fainter star to either side. Aquila is crossed by the Milky Way, and is very rich in star-fields.



Below Altair may be seen a line of three stars – Theta, Eta, and Delta Aquilæ. The central member, Eta, is of special interest, as it is a Cepheid variable. The magnitude range is from 3·7 to 4·5, and the period is 7·2 days, so that the fluctuations may be followed with the naked eye and are quite obvious, from one night to the next. Suitable comparison stars, all in Aquila, are Theta (magnitude 3·3), Delta (3·4), Beta (3·9) and Iota (4·3).

Eta Aquilæ ranks with Delta Cephei and Zeta Geminorum as the brightest of its class; had it been studied first, these vitally important variables might well have been called Aquilids! Delta Cephei, which is very high during summer evenings and is circumpolar from Britain, has a range of from 3·7 to 4·3 and a

period of 5·4 days. According to the famous period-luminosity law, it follows that Eta Aquilæ must be more powerful than Delta Cephei; and as the two appear equally bright (or virtually so), Eta must be the more remote.

Not many Cepheids are conspicuous objects with the naked eye. The brightest members of the class are given in the following table:

Star	*Max.*	*Min.*	*Period days*
Zeta Geminorum	3·7	4·3	10·15
Eta Aquilæ	3·7	4·5	7·18
Delta Cephei	3·7	4·3	5·37
Kappa Pavonis	4·0	5·5	9·08
Beta Doradûs	4·5	5·7	9·84

In addition to these Cepheids, there are others (such as Polaris) whose fluctuations are too slight to be detected with the naked eye. Kappa Pavonis and Beta Doradûs are, of course, too far south to be seen from anywhere in Britain.

Venus and Regulus

On 8 July Venus lies less than half a degree from Regulus, the first-magnitude star in the Sickle of Leo. Sixteen years ago – on 7 July 1959 – there was an actual occultation of Regulus. The phenomenon took place in broad daylight, but many observers were able to watch it; a telescope of 12 inches aperture proved to be quite adequate.

In those days, before the first planetary probes were sent up, not a great deal was known about the height of Venus's atmosphere, and the occultation was regarded as important. Regulus would be expected to fade appreciably before disappearing behind the solid body of the planet, and the extent of the fade would give a clue to the height of the atmosphere responsible for it. The results were closely analysed, and indicated a value which was very similar to that found later by the U.S. Mariners and the Russian Veneras. It will be centuries before Venus again occults a first-magnitude star.

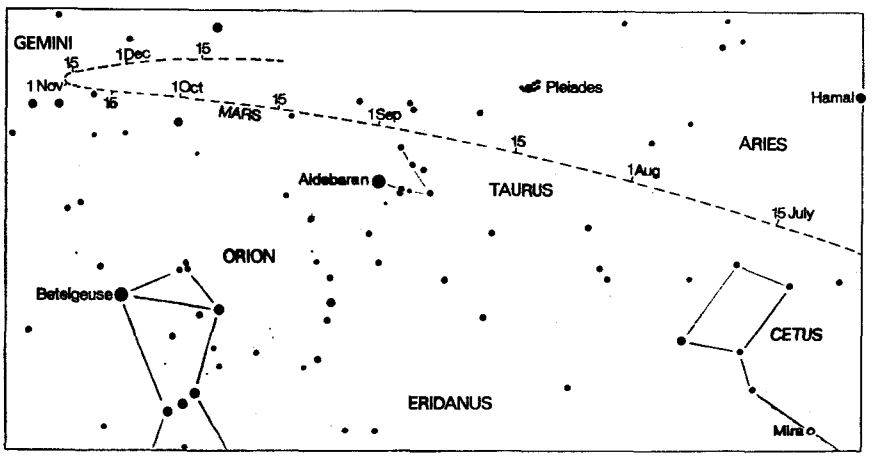
August

New Moon: 7 August *Full Moon:* 21 August

Mercury is in superior conjunction on 1 August, and will not be visible. Towards the end of the month it becomes an evening star, but sets soon after the Sun and is not likely to be seen.

Venus moves rapidly round to inferior conjunction on 27 August, and disappears from the evening sky. At this time it is at its nearest to the Earth – rather less than 27 million miles – but the dark side of the planet is towards us.

Mars now rises before midnight and will be seen in the constellation Taurus. The planet passes south of the Pleiades in the middle



Mars, July - December, 1975

of August. At midnight on 30 August, Mars will be seen very close to the Moon (which is then at Last Quarter), and this will actually give rise to an occultation, but this is visible only in equatorial regions. Mars is now growing noticeably brighter (magnitude +0·6 to +0·3) as its distance from the Earth decreases.

Jupiter rises in the east before midnight, and reaches a stationary point on 15 August, after which it begins to move retrograde for the next four months. On 12 August, Jupiter is at perihelion, when it comes nearest to the Sun in its twelve-year journey. Its distance is then about 460 million miles (740 million km), so that the planet is nearly 50 million miles nearer to the Sun than it was at aphelion in 1969, and is now at its most brilliant (magnitude −2·1 to −2·3 during August, increasing to −2·5 at opposition).

Saturn now begins to appear as a morning star, and by the end of the month it rises about three hours before the Sun. It will then have passed from Gemini into Cancer, and as it rises in the east it will be seen below the figure of Gemini, bright enough (magnitude +0·4) to be readily distinguished.

The Perseids

Of all annual meteor showers the Perseids are the most reliable; they never fail to provide a good display, though there are years in which the spectacle is spoiled by moonlight. In 1975, however, the Moon is out of the way; and, clouds permitting, the Perseids should be seen in their full glory. The shower lasts for several weeks; it is at its maximum around August 12.

Meteor recording is one of those branches of astronomy which can be carried out with the naked eye; for obvious reasons, telescopes and binoculars are of no help. The observer can plot the path of each meteor seen, referring it to known stars; he can estimate the magnitude, and can note any unusual behaviour or colour. It must be admitted that the introduction of radar methods has, to some extent, reduced the value of amateur work; but meteor observations are still useful – and studying the Perseid

shower during a warm August night is more pleasurable than a long spell observing the Ursids in mid-December.

EPSILON PEGASI AND SUSPECTED VARIABLE STARS

Pegasus, the Flying Horse, is distinguished by the four stars which make up the famous Square (even though one of them, Alpheratz, has for some unknown reason been wrenched away from the constellation and is now known as Alpha Andromedæ instead of, as formerly, Delta Pegasi). The other bright star in Pegasus is Epsilon, sometimes still called by its old proper name of Enif. The official magnitude is 2·3; but it has been suspected of variability, and interested observers may care to keep an eye on it. It is a highly luminous K-type giant, at a distance of 780 light-years.

There are various bright naked-eye stars which have been suspected of slight fluctuations; we can even include Shedir or Alpha Cassiopeiæ, in the famous W, though here the variations do seem to be fairly well authenticated. Of course, precise measurements involve the use of special photometric equipment; but it is not impossible that a few of the suspected variables may occasionally show bursts or fades marked enough to be noticed with the naked eye. Typical cases are as follows:

Beta Ceti – Official magnitude 2·0; suspected of occasional brief rises to 1·6 or thereabouts. Its isolation makes comparisons difficult. Comparison stars are Alpha Andromedæ (2·1) and Alpha Arietis (2·0); but allowance must be made for extinction, since Beta Ceti is well to the south of either of these comparison stars. It is a K-type giant, 57 light-years away, and its orange hue is well seen in binoculars.

Beta Corvi – Official magnitude 2·7. In an old catalogue by Chambers it was listed as definitely variable between magnitudes $2\frac{1}{2}$ to $3\frac{3}{4}$, but this seems most unlikely. Comparisons: Gamma Corvi (2·6) and Delta Corvi (3·0). Beta is of type G; distance 108 light-years.

Beta Cygni – Albireo, the faintest star of the Cross of Cygnus,

and the loveliest coloured double in the sky. Official magnitude 3·1. The last-century astronomer Klein believed it to fluctuate very slowly between magnitudes 3 and 4, but this is probably wrong. Albireo is of type K, 410 light-years from us. If it were seen from the standard distance of 10 parsecs its magnitude would be —2·4, roughly the same as that of Jupiter.

Epsilon Draconis – Circumpolar in Britain. Official magnitude 4·0; comparisons Chi Draconis (3·7) and Phi Draconis (4·2). There is probably no real change.

Gamma Eridani – Official magnitude 3·0; Secchi, in the last century, believed (no doubt erroneously) that it ranged between $2\frac{1}{2}$ and $3\frac{1}{2}$; comparison stars, Beta Eridani (2·8) and Delta Eridani (3·7).

Beta Leonis – Denebola, in the 'triangle' of Leo some way from the Sickle. Spectrum A; distance 43 light-years. Here we do have some evidence of variation, and it is notable that ancient astronomers ranked it as of the first magnitude. Comparisons: Gamma Leonis (2·0) and Delta Leonis (2·6). The plan for observing it is to look at it and Gamma to see whether there is any detectable difference, since Beta is officially ranked as 2·1.

Epsilon Pegasi – Official magnitude 2·3; comparisons Alpha Pegasi (2·5) and Gamma Cygni (2·2). Schwabe, a century ago, gave the range as from 2 to $2\frac{1}{2}$, and even gave a period of $25\frac{3}{4}$ days; but there is no evidence of this, and if any fluctuations occur they must be very slight and occasional.

Delta Ursæ Majoris – Megrez, the faintest of the seven Plough (or Big Dipper) stars, is ranked as of magnitude 3·3, but in ancient times it was recorded as equal to the other stars in the Plough pattern, so that it may be at least a secular variable. It is possible that there may now be occasional falls to magnitude $3\frac{3}{4}$. Comparisons: Alpha Draconis (3·6), Psi Ursæ Majoris (3·3), Kappa Draconis (3·8).

Eta Virginis – Official magnitude 4·0; Gould, in the nineteenth century, claimed a variation between 3 and 4. Comparison star: Beta Virginis (3·8).

Extinction – the loss of light of a star near to the horizon, due

absorption in the Earth's atmosphere – is very important when making naked-eye estimates; if you can, choose a comparison star whose altitude is much the same as that of the variable or suspected variable. Extinction amounts to 2·5 magnitudes at an altitude of 2 degrees; 1 magnitude at 10 degrees; 0·4 magnitude at 21 degrees, and 0·1 magnitude at 43 degrees.

It is not really very likely that any fluctuations will be found in any of the stars listed here, but Beta Leonis, Epsilon Pegasi, and Delta Ursæ Majoris do merit some attention just in case they show any unusual behaviour. The chances are very slight, but not nil!

September

New Moon: 5 September *Full Moon:* 20 September

Equinox: 23 September

Mercury is at greatest eastern elongation (27°) on 13 September, and is then an evening star, but it will be too low in the western sky to be seen in the twilight.

Venus begins to appear in the east as a morning star, moving out from the Sun quite rapidly. By the end of the first week of September it rises an hour before sunrise, and by the end of the month it will precede the Sun by more than three hours. The planet is then a brilliant object of magnitude −4·3.

Mars rises to the north of east in mid-evening, and will be seen in the south at sunrise. The planet is still moving direct in Taurus, and passes four degrees north of Aldebaran on 1 September. Mars is now a conspicuous object, its magnitude changing during the month from +0·3 to −0·2. This increase of half a magnitude represents an increase of brightness of nearly sixty per cent.

Jupiter is now approaching opposition and rises in the east shortly after sunset, a brilliant object reaching magnitude −2·5 during the month. With the coming of the darker evenings it will now be possible to see Jupiter against a really dark sky, and the ever-changing positions of the four great satellites are always interesting to follow with a small telescope.

Saturn rises shortly after midnight to the north of east. It is still in

Cancer, and will be seen below the figure of Gemini, almost in a line with the Twins, Castor and Pollux, but brighter than either of these stars. A small telescope will show the splendid rings and the satellite Titan.

Vesta comes to opposition on 18 September on the borders of Aquarius and Cetus. This minor planet reaches magnitude +6·2 at opposition, and it may be found with the aid of a pair of binoculars. The diagram on page 79 shows part of the apparent path of Vesta at this time. See also the notes on page 116.

THE FIRST LANDING ON THE MOON: SEPTEMBER 1959

Now that rockets to the Moon have become so much a part of practical space-research, it is interesting to cast one's mind back to another September: that of 1959, when the first direct contact was made. In those far-off days the Russian experiments were much more successful than the American, and there were many people who believed that the initial manned landing would be by a Soviet cosmonaut. Certainly the Russians had an impressive series of 'firsts', and their probe Luna 2 deserves to be much more widely remembered than it actually is.

The United States attempts came first, and began on 17 August 1958 with a vehicle whose lower launching-stage exploded after a mere 77 seconds of flight. Pioneer 1 (11 October 1958) reached just over 70,000 miles; Pioneer 2 (9 November) was a total failure, as the third stage of the launcher failed to ignite; Pioneer 3 (6 December) attained 66,000 miles – but, like its predecessors, went nowhere near the Moon. Then, on 2 January 1959, the Russians came into the picture, and sent Luna 1 past the Moon at only 4,660 miles; contact was maintained, and valuable information obtained – for instance, confirmation that the Moon has at best a very weak magnetic field. America's Pioneer 4 (3 March 1959) did at least go within 37,000 miles of the Moon, but was of no real scientific value in so far as lunar research was concerned.

Then, on 12 September 1959, the Russians sent up Luna 2. An artificial sodium cloud was released *en route*, and throughout the

flight signals were clearly received – not only in the U.S.S.R., but also at Jodrell Bank, where Sir Bernard Lovell and his team kept constant vigil. There is not the slightest doubt that Luna 2 hit the Moon at $21^h\ 2^m\ 23^s$ G.M.T. on 13 September; the signals stopped abruptly at the moment of impact. It is thought that the landing-area was somewhere in the Mare Imbrium, probably not too far from the 50-mile crater Archimedes.

Luna 2 was intended to do no more than make a crash-landing; it achieved its object – and one day, no doubt, its wreckage will be found and removed to some lunar museum! It paved the way for the great triumph of the following month, when Luna 3 went right round the Moon and sent back the first pictures of the far side which can never be seen from Earth because it is always turned away from us. During the next few years the Americans had failure after failure; but at last, in July 1964, Ranger 7 sent back more than four thousand photographs of the Moon from close range before it impacted, and the whole situation was transformed. Only five years later, Neil Armstrong and Edwin Aldrin stepped out on to the bleak rocks of the Mare Tranquillitatis.

The Colour of Mars

While Mars is close to Aldebaran, in early September, it will be interesting to compare the colours of the two objects. Aldebaran, with its K-type spectrum, is not so red as Antares or Betelgeux, which are of type M; but it is at least strongly orange, as any naked-eye observer can see. This month Mars is more than half a magnitude the brighter of the two, and its redness will be the more noticeable; but the colour is probably affected to some extent by conditions in the Martian atmosphere. Amateurs who like experimenting with colour photography will be wise to take advantage of this month's close conjunction of a red planet with an orange-red giant star.

Fomalhaut: and the Nearest First-Magnitude Stars

Fomalhaut, in Piscis Australis (or Piscis Austrinus), the Southern Fish, is at its best in September evenings so far as

British observers are concerned. It is the southernmost of the first-magnitude stars ever visible from the latitude of London or New York, and it may be found by using the Square of Pegasus as a 'direction-indicator' (see Star Charts 9L and 10R). The only possible confusion is with Beta Ceti, which is however considerably fainter.

Fomalhaut is a relatively near neighbour; it is a mere 24 light-years away. There are only nine first-magnitude stars within 50 light-years of us: they are as follows:

Star		*Apparent Magnitude*	*Spectrum*	*Distance, lt.-yrs*	*Luminosity Sun = 1*
	Alpha Centauri	−0·27	G	4·3	1·1
Sirius	Alpha Canis Majoris	−1·43	A	8·6	26
Procyon	Alpha Canis Minoris	0·37	F	10	5
Altair	Alpha Aquilæ	0·80	A	16	9
Fomalhaut	Alpha Piscis Austr.	1·16	A	24	13
Vega	Alpha Lyræ	0·04	A	27	50
Pollux	Beta Geminorum	1·16	K	32	28
Arcturus	Alpha Boötis	−0·06	K	41	100
Capella	Alpha Aurigæ	0·05	G	47	150

Of these, Alpha Centauri is a fine binary (the spectrum and luminosity given here refer to the brighter component); Capella is a very close binary; Sirius and Procyon have White Dwarf companions.

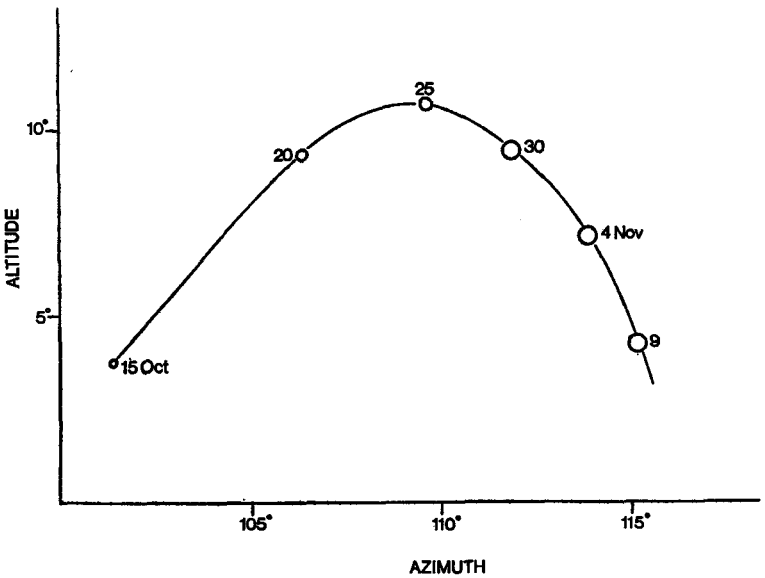
Fomalhaut can never be seen to advantage from northern countries, and one has to go south to appreciate how prominent it really is – particularly since there are no other bright stars in its area. It is rather surprising to find that the Southern Fish is one of the original 48 constellations listed by Ptolemy in the second century A.D. No telescopic objects of interest to the amateur observer are to be found in it.

October

Summer Time in Great Britain and Northern Ireland ends on 26 October.

New Moon: 5 October *Full Moon:* 20 October

Mercury is in inferior conjunction on 9 October and will not be visible until the end of the month. The planet reaches greatest western elongation (18°) on 25 October, and will then be well placed for observation as a morning star. The diagram shows the



Mercury, October

changes in altitude and azimuth of Mercury on successive mornings when the Sun is six degrees below the horizon; this is about 35 minutes before sunrise in October. The changes in brightness are roughly indicated by the size of the circles, and it will be seen that Mercury is brightest after the date of western elongation.

Venus is a splendid object in the morning sky, rising in the east at about 3^h. The planet reaches its greatest brilliancy (magnitude −4·3) on 3 October, and may then be seen in a dark sky near the head of Leo; it passes about four degrees south of Regulus on 6 October.

Mars rises in the north-east in mid-evening, and continues to increase rapidly in brightness (magnitude −0·2 to −0·7). The planet moves into Gemini in mid-October, and at the end of the month forms a little group with the stars at the feet of the Twins, where it will be quite a conspicuous object.

Jupiter is at opposition on 13 October and is a brilliant object in Pisces, with no other bright stars in the neighbourhood. This opposition occurs when Jupiter is near perihelion (see August notes), so that the planet is at its minimum distance from the Earth (368 million miles, or 592 million km) and at its brightest, at magnitude −2·5. This is fully half a magnitude brighter than it was at the least favourable opposition in 1969.

Saturn rises before midnight in Cancer, and is bright enough (magnitude +0·4) to be easily recognized. As it rises to the north of east the Twins, Castor and Pollux, will be seen above it and the star Procyon round to the south (see the lower figure of star chart 11R).

Five planets will be visible in the sky just before dawn in the last week of October. In order, from west to east, they are Jupiter, Mars, Saturn, Venus and Mercury.

The Great Spiral

October evenings are dominated by the Square of Pegasus and its neighbours. Extending away from the Square may be seen the line of stars marking Andromeda – the chained princess of the famous old legend involving Perseus, Cassiopeia, and Cepheus, though in the sky it can hardly be said that there is any distinctive shape at all. The constellation contains various objects of interest, but the most important of all is without doubt the Great Spiral, Messier 31.

M.31 is the largest member of the local group of galaxies, and is a system considerably bigger than our own Galaxy. It is visible with the naked eye, and was described in the year 964 by Al-Sûfi, who called it 'a little cloud'. For some strange reason it was not mentioned by Tycho Brahe, and the first telescopic observation of it seems to have been made by Simon Marius in 1612: 'like the flame of a candle seen through horn'.

Many comments on it were made during the following years, but it was Lord Rosse, using his great 72-inch reflector at Birr Castle from 1845, who considered that it could be wholly resolved into stars. It had become clear that there were two types of nebulæ; those which were resolvable (such as M.31) and those which were not, appearing to be gaseous (such as M.42 in Orion's Sword). The vital question was, of course, whether the starry nebulæ were members of our own system, or whether they lay far beyond. The problem was solved only in the 1920s, following Hubble's work at Mount Wilson. The 100-inch telescope enabled him to study Cepheid variables in M.31 and a few other systems; since the distances of these Cepheids could be worked out from the period-luminosity law, the distances of the systems in which they lay could be found – and it was at once clear that M.31 was indeed a galaxy in its own right. The distance originally given was 750,000 light-years, but an error in the Cepheid scale, not discovered until much later, has led to the modern value of 2,200,000 light-years.

In 1885 the supernova S Andromedæ blazed out in M.31. (The remarkable story of its discovery has been described in the October

notes for the 1974 Yearbook.) Astronomers of today wish that the outburst had occurred later, so that it could have been studied with modern equipment; in 1885 there were serious doubts as to whether the star had anything to do with the Spiral! Many ordinary novæ have been seen in the system, but it may be a long time before another supernova appears there. At least 300 globular clusters have been found surrounding the Spiral, and there are also several known planetary nebulæ associated with it. Holmberg has stated that the total mass of M.31 is more than 300,000 million times that of the Sun.

Though M.31 is the nearest of the really large galaxies, it is not nearly so spectacular as might be thought when seen through a small or even a moderately large telescope. In fact, it has to be ranked as very disappointing indeed when compared with, for instance, the beauty of the gaseous nebula in Orion's Sword. M.31 appears as nothing more than a blur of light; the spiral structure is not evident, and cannot be well seen except by means of photographs taken through giant instruments. Moreover, the system lies at a narrow angle to us, so that the 'Catherine-wheel' effect is largely lost.

M.31 has two elliptical companions, M.32 and NGC 205, both of which are easy telescopic objects. M.32, the more conspicuous of the two, has about one-hundredth the mass of the Spiral.

Venus and Jupiter Compared

Both Venus and Jupiter are visible in the morning sky during October, so that they may be compared with each other. Both are almost at their best. Venus attains magnitude −4·3, and for once in a way it may be seen against a dark sky; it may be expected to cast shadows, and there is considerable interest in checking this. Jupiter, too, is almost as bright as it can ever be, because it is not only at opposition but is also near perihelion. The magnitude reaches −2·5; when opposition occurs near aphelion (as in 1969) the maximum is only −2. Yet because Jupiter is so brilliant, and there is nothing suitable with which to compare it, few people

realize that the difference in brightness between perihelic and aphelic oppositions is very considerable.

Yet Venus remains supreme; its closeness and its layer of reflective clouds earn it the honour of being named after the Goddess of Beauty. It is at its brightest when at the crescent stage, as now; when more of the illuminated hemisphere is turned toward us, the distance from Earth is much greater, so that the apparent diameter is correspondingly less.

Mars is also on view during the mornings this month. At its best it can outshine Jupiter, but it will not do so this year; at opposition, in December, it will be only a little superior to Sirius, the brightest of the stars.

Mira

Cetus, the Whale (or the sea-monster of the Perseus legend) has now come back into view in the late evening; but there is one difference from the view obtained earlier in the year. Mira was then near maximum; now it is well below naked-eye visibility, and it will not come back into naked-eye range until near the end of 1975.

November

New Moon: 3 November *Full Moon:* 18 November

Mercury may possibly be seen in the first few days of the month (see note and diagram in October notes) as a morning star, but it is in superior conjunction on 28 November, and will not then be visible.

Venus reaches its greatest western elongation (47°) on 7 November, and although it begins to rise a little later each morning, it will still be seen in the eastern sky for four hours before sunrise. Its brightness also decreases (magnitude −4·1 to −3·9) as its distance from the Earth increases, but this is hardly likely to be noticeable in so brilliant a planet. Venus passes about five degrees north of Spica on 29 November.

Mars reaches a stationary point on 6 November, just inside the western boundary of Gemini, and then begins its retrograde motion before reaching opposition. The planet moves back into Taurus towards the end of the month. Mars rises to the north of east just after sunset, and will be visible all night. There is an even more rapid increase in brightness during the month (magnitude −0·7 to −1·4) and by the end of November it will be almost as bright as Sirius, although the colours of the two are very different.

Jupiter is moving retrograde in Pisces, and sets in the west before dawn. Although fading to magnitude −2·3 during the month, it remains brighter than any other star or planet until Venus rises in the east.

Saturn reaches a stationary point in Cancer on 15 November, and then begins to move back towards Gemini. The planet rises in the late evening and grows slightly brighter during the month (magnitude +0·4 to +0·3). Some degrees to the east of Saturn is the interesting star cluster Præsepe, M.44, which lies between the two fourth magnitude stars Gamma and Delta Cancri.

A partial eclipse of the Sun on 3 November is visible only in Antarctic regions. See notes on page 110.

A total eclipse of the Moon on 18-19 November is visible in Europe and the north-eastern parts of North America. Totality will last from $22^h\,03^m$ to $22^h\,44^m$ G.M.T.

THIS MONTH'S LUNAR ECLIPSE

The lunar eclipse of 18-19 November is total for less than three-quarters of an hour, but will be well worth watching. Details are given on page 110. To the casual observer, the main interest centres upon the colours, which are sometimes remarkably beautiful; everything depends upon the conditions in our own air – since any light from the Sun reaching the Moon during totality must be refracted through the atmosphere of the Earth. There are some occasions, as in 1848, when the Moon remains very bright throughout; but at other eclipses the Moon has been known to become so dim that it has been hard to locate even with the aid of binoculars or a telescope. Colour photography may be attempted, of course.

It has been suggested that some features of the lunar surface show definite changes during and after totality, because of the sudden cooling; this applies particularly to the famous Linné (see November notes, 1974 Yearbook). Most authorities are (justifiably) very sceptical, but it is certainly worth making a check of some of the brightest and darkest regions before, during and after the eclipse, to see whether any alterations are detectable. Suitable features are Censorinus, Dionysius, Euclides, Lichtenberg, Tycho, and Copernicus (bright) and the floors of Grimaldi,

Riccioli, Billy, Plato, Alphonsus, and Crüger (dark or dark-patched). It is most unlikely that any positive results will be obtained – but one never knows!

Richard Carrington

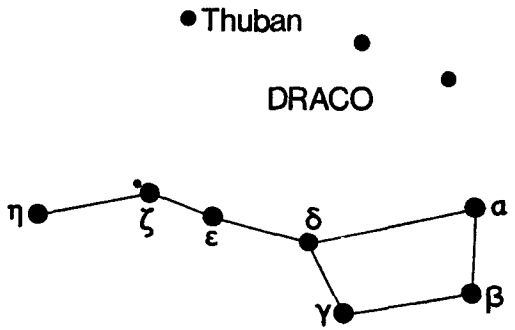
Richard Christopher Carrington, who died on 27 November 1875, was one of the leading solar observers of the nineteenth century. He was born in London in 1826, and educated at Cambridge; after a spell in Durham he built and equipped a private observatory at Redhill in Surrey. He carried out a survey of the northern circumpolar stars, but his main work was in connection with the Sun. Independently of Spörer, he discovered the Sun's equatorial acceleration, and also the law of sunspot zones; at a new cycle the spots appear in relatively high latitudes, but as the cycle progresses spots are seen closer and closer to the equator – though they die out before reaching the equator itself, while the first spots of the new cycle have started to appear in high latitudes. Spörer was the first to announce this law, which is, appropriately, named after him; but Carrington's discovery was independent.

Carrington continued to observe the Sun as energetically as his business career allowed, but unfortunately he could do little after 1865, when his health broke down. He died at Churt, in Surrey, after a long illness.

Thuban – the Former Pole Star

During November evenings the Great Bear, Ursa Major, is at its lowest to observers in Britain and the United States; the 'Plough' never sets over any part of the British Isles, though some of the fainter stars of the whole constellation do drop below the horizon. The Pole Star may be found by using the two Pointers, Merak and Dubhe; it is within a degree of the polar point, and so seems to remain almost stationary in the sky.

This has not always been the case. Because of precession, the celestial pole moves slowly but steadily, and at the time when the Egyptians built their Pyramids the pole lay close to a much fainter star – Thuban, or Alpha Draconis.



Thuban is easy to locate. It lies almost midway between Mizar or Zeta Ursæ Majoris, the famous binary in the Plough, and the 'Guardian of the Pole', the orange second-magnitude star Kocab or Beta Ursæ Minoris. The magnitude is 3·6, so that Thuban is by no means prominent; it is rather fainter than Megrez, the dimmest of the seven Plough stars. Thuban is white, with a spectrum of type A; and it is much more luminous than the Sun. It is, in fact, more powerful than any of the Plough stars apart from Dubhe and Alkaid, but its distance from us is well over 100 light-years.

To indicate the real luminosity of a star, astronomers make use of what is called 'absolute magnitude'. This may be defined as 'the apparent magnitude that a star would have if it could be seen from a standard distance of 10 parsecs, or 32·6 light-years'. (One parsec is the distance at which a star would show a trigonometrical parallax of one second of arc; actually no star, not counting the Sun, is as close as this.) If Thuban could be seen from this standard distance, it would shine gloriously with a magnitude of −0·5 – brighter than any star we actually see in the sky apart from Sirius and Canopus.

In 12,000 years' time, precession will have moved the north celestrial pole round to a point not far from Vega, in Lyra. Vega is a brilliant blue star, now visible in the north-west; it looks very imposing – and yet its absolute magnitude is only +0·5, so that

it is not nearly so powerful as Thuban. As so often happens in astronomy, appearances are deceptive.

Though Thuban is catalogued as Alpha Draconis, it is not the apparently brightest star in the constellation; two of the stars in the Dragon's head, near Vega, are above the third magnitude. Draco is a long, sprawling group, but it is not hard to identify, and the diagram given opposite will show where to find it.

December

New Moon: 3 December *Full Moon:* 18 December

Solstice: 22 December

Mercury begins to appear as an evening star at the end of December, and may possibly be seen low in the south-west shortly after sunset.

Venus continues to be visible as a brilliant object in the morning sky, rising in the south-east about three hours before the Sun. (Magnitude −3·8 to −3·6.)

Mars is at opposition on 15 December, when it will be seen in Taurus, well north of the figure of Orion. Owing to the eccentric orbit of Mars, the planet is nearest to the Earth on 9 December, at a distance of 53 million miles (85 million km), when its magnitude reaches −1·6. Although the planet is well placed for observation, it is very much farther from us than at the favourable opposition of 1971, when it was only 35 million miles from the Earth. The next opposition of Mars occurs on 22 January 1978, and although this interval of 769 days seems unusually long, it is actually *less* than the average 780 days (see page 54). The interval depends on the position of the planet in its orbit, and is another effect of the eccentricity:

10 August 1971 to 25 October 1973 = 807 days
25 October 1973 to 15 December 1975 = 781 days

Jupiter reaches a stationary point on 11 December and then moves

direct again through Pisces. The planet sets shortly after midnight in the west, and by the end of the year it will have faded to magnitude −2·1.

Saturn rises shortly after sunset and grows brighter (magnitude +0·2 to 0·0) as it approaches opposition in January 1976. The planet is in Cancer, and is moving retrograde. By the end of the month it will be seen below the figure of Gemini, and once again in line with the Twins, Castor and Pollux.

MARS – WORLD OF VOLCANOES

Though Mars is not so close this year as it was in 1971 or 1973, it is in the northern hemisphere of the sky, and is excellently placed for observers in Britain and the United States. The diameter will reach nearly 17 seconds of arc, and the south pole of the planet will be displayed.

A modest telescope will show the main surface features of the planet; the darkest areas, such as the Syrtis Major, are visible with a 3-inch refractor. Unfortunately, serious observing programmes do require the use of high magnifications, which means that a telescope of fair aperture is needed; no really useful research can be carried out with a refractor below 5 inches, or a reflector below 8 inches (though the 'lowest limits' are a matter for debate, and different observers have different ideas on the subject).

The Mariner probes have shown that Mars is a world of giant volcanoes, huge craters and deep valleys; the old idea of a rather featureless surface, devoid of high mountains, has proved to be completely wrong. It has also been found that the atmosphere is depressingly thin. Nowhere does the ground pressure attain 10 millibars, whereas the pre-Mariner value was given as 85 millibars. Though the white polar caps contain some water ice, they seem to be made up chiefly of solid carbon dioxide; and all things considered, it seems rather unlikely that there is any life on Mars. The most we can expect is something very primitive, and there is a real chance that the planet is totally sterile.

Yet Mars remains probably the most intriguing of all the planets in the Solar System; and despite the probes, there is still work for the ground-based observer to do. Whether or not Mars supports life, it is certainly not inert. There are clouds in the atmosphere; and it is important to study them, both to see how often they appear and to attempt to track their movements from night to night. Moreover, there are times when tremendous dust-storms arise, blotting out even the most famous dark areas for weeks or even months at a time. It seems that really major storms are most likely to occur some weeks after a favourable opposition passage; thus the 1971 dust-storm, which covered the planet at the time when Mariner 9 arrived, began in November (opposition had occurred in August). There was also a major dust-storm in 1973. Whether anything comparable will occur in 1975 remains to be seen.

Since the southern hemisphere of Mars will be displayed, the V-shaped Syrtis Major will be much in evidence. This is the most prominent of all the dark areas; it was once known as the Kaiser Sea or the Hourglass Sea, and was drawn by Christiaan Huygens as long ago as 1659. It was originally thought to be low-lying, perhaps representing an old sea-bed; we now know it to be high. South of it is Hellas, a circular feature which can sometimes appear so bright that unwary observers have mistaken it for the polar cap – though it was not brilliant during the 1973 opposition. Hellas, once regarded as a plateau, is in fact the deepest known depression on Mars, and the Mariner photographs have shown that it is almost devoid of detail, though the surrounding regions are cratered.

Westphal's Comet – and Others

Westphal's Comet, with its period of almost 62 years, was described as 'pretty bright' by its discoverer in 1852; but during the 1913 return it became diffuse as it approached perihelion, and faded by ten magnitudes in six weeks! Though its orbit is well known, its recovery cannot therefore be guaranteed, and in any case it will not become conspicuous. Careful searches will be made for it as soon as it comes within possible range.

There are only a few comets with periods of more than twenty years which have been observed at more than one return. They are as follows:

Comet	*Period*	*Last return*	*Next predicted return*
Crommelin	27·9	1956	1984
Tempel-Tuttle	32·9	1965	1998
Stephan-Oterma	37·8	1942	1980
Westphal	61·9	1913	1975
Brorsen-Metcalf	69·1	1919	1988
Olbers	69·6	1956	2026
Pons-Brooks	70·9	1954	2025
Halley	76·0	1910	1986
Herschel-Rigollet	156	1939	2095
Grigg-Mellish	164	1907	2071

Of these only Halley's is a prominent naked-eye object. Crommelin's Comet is one of those named after the mathematician who worked out its orbit – the late A. C. D. Crommelin, who showed that comets discovered at different returns by Pons, Coggia, Winnecke, and Forbes respectively were one and the same. It was also Crommelin, together with his colleague Cowell, who made the very exact calculations of the return of Halley's Comet in 1910.

There are some comets which must be regarded as 'lost'. The most famous of these is Biela's, which divided in two in 1846, was seen again in its dual form in 1852, and thereafter disappeared altogether, though it is certainly associated with a now very feeble meteor shower. Incidentally, it was while carrying out an unsuccessful search for Biela's Comet in 1973 that Dr Lubos Kohoutek, at Hamburg, discovered the comet which was expected to become brilliant around Christmas 1973, but which proved to be so disappointing. The period of Kohoutek's Comet is of the order of 75,000 years.

Meantime, Westphal's Comet may or may not be recovered. If not, then it must be added to the list of comets which have become defunct.

Eclipses in 1975

In 1975 there will be four eclipses, two of the Sun and two of the Moon.

(1) *A partial eclipse of the Sun* on 11 May will be visible in northern Asia, the whole of Europe, and in Greenland and the Arctic. In southern England the eclipse begins at $5^h\ 24^m$ G.M.T. and reaches a maximum at $6^h\ 19^m$, when 55 per cent of the Sun will be covered by the Moon. The eclipse ends at $7^h\ 18^m$. At more northerly stations, the various stages of the eclipse will occur a few minutes later, and rather more of the Sun will be obscured.

(2) *A total eclipse of the Moon* on 25 May will be visible in North and South America. The eclipse begins at $4^h\ 00^m$ G.M.T., and in the British Isles the Moon will then be setting. The total phase begins at $5^h\ 03^m$ and ends at $6^h\ 33^m$, the shadow of the Earth passing finally from the Moon at $7^h\ 36^m$.

(3) *A partial eclipse of the Sun* on 3 November is visible only in Antarctica and the extreme south of South America.

(4) *A total eclipse of the Moon* on 18 November is visible in Africa, the British Isles and the rest of Europe, and in the north-east of North America. The eclipse begins at $20^h\ 39^m$ G.M.T. and becomes total at $22^h\ 03^m$. Totality ends at $22^h\ 44^m$ and the eclipse ends at eight minutes after midnight.

Occultations in 1975

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than five degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about twenty degrees a year, a complete revolution taking 18·6 years, during which time all the stars that lie within about six and a half degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star but only a few of these occultations will be visible at any one place in hours of darkness. A typical example of this behaviour is shown by a series of occultations of Spica which begins in March, and will continue until the end of 1976. At first these events will be visible only in the southern hemisphere, but they slowly work their way north, and will be seen in northern latitudes in August 1976.

There are only four first magnitude stars that can be occulted by the Moon; these are Regulus, Aldebaran, Spica, and Antares, but Spica alone is affected in 1975. Of the planets, Mercury, Venus, and Mars will all be occulted during the year, but only one of these events is to be seen in northern latitudes. This is the occultation of Mercury on 7 July – a very difficult observation in broad daylight.

Comets in 1975

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the Sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no records of the previous appearances of these bodies, and we are unable to follow their wanderings through space.

Comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention from astronomers. Unfortunately they are all faint objects, and are recovered and followed by photographic methods using large telescopes. Most of these short-period comets travel in orbits of small inclination which reach out to the orbit of Jupiter, and it is this planet which is mainly responsible for the severe perturbations which many of these comets undergo. Unlike the planets, comets may be seen in any part of the sky, but since their distances from the Earth are similar to those of the planets their apparent movements in the sky are also somewhat similar, and some of them may be followed for long periods of time.

The following table compares the numbers of newly discovered comets, successfully predicted returns, and comets still being followed from previous years:

	1970	*1971*	*1972*
New discoveries	6	1	6
Predicted and recovered	11	5	6
Still under observation	10	14	9
Totals	27	20	22

Data for 1973 are not yet complete, but nine new comets were

discovered and six more were recovered as the result of successful predictions. Of the new discoveries three proved to be short-period comets, one of which (1973 *d*), discovered by Dr T. Gehrels of the University of Arizona, was found to be identical with periodic comet Swift (1), which had not been seen since its original discovery in 1889. In the interval the comet had made nine revolutions (period 9·2 years) without being detected. Comet Kohoutek, which failed to do justice to the extravagant expectations of press and television, was the second of two comets discovered by Dr L. Kohoutek at Hamburg in the early months of 1973. Its failure to reach the expected brightness is not in the least remarkable, for we do not yet know the laws which govern the stellar magnitude of such objects.

The number of comets under observation in any one year varies considerably, but is much greater than is generally supposed. Thus 1970 created something of a record, since not only were 27 comets under observation, but three of these were naked-eye objects, while four others were easily visible in binoculars.

In 1975 the following periodic comets may be recovered:

Comet Arend was first seen in 1951, and was recovered at its returns in 1959 and 1967. It is a faint comet with a period of 7·76 years.

Comet Perrine-Mrkos was discovered by Perrine in 1896 and was seen again in 1909. It was then lost for many years but was recovered by chance by Mrkos in 1955, and was seen again in 1962 and 1968. At its last appearance it was followed for about three months, but was no brighter than magnitude 12. The period of this comet is 6·72 years.

Comet Westphal travels in a much larger orbit and has a period of 61·9 years. At aphelion it travels out as far as the orbit of Neptune, but it is inclined at the large angle of 41°. It was discovered in 1852, was seen again in 1913, and is expected to return towards the end of 1975.

Comet Wolf was discovered in 1884 and had made eleven returns to perihelion at its last appearance in 1967. The original orbit had a period of 6·8 years, but a close approach to Jupiter in 1922 enlarged the orbit so that the period became 8·4 years. This orbit is very well defined since it has been the subject of intensive study by the Polish astronomer Michael Kamienski (1879-1973), who was able to demonstrate the fact that the mean motion of the comet is slowly decreasing. This was one of the first examples known of the action of non-gravitational forces on the motion of a comet. Unfortunately this is a very faint comet, but it may be recovered at the end of 1975.

Comet Schwassmann-Wachmann (1) has a nearly circular orbit with a period of sixteen years, which lies entirely between the orbits of Jupiter and Saturn. The motion of this comet is very much like that of a planet, and it is visible each year. It is remarkable for its sudden outbursts of brightness, which seem to have some connection with solar activity.

Meteors in 1975

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted – only on very rare occasions have the meteors been so numerous as to resemble snowflakes falling.

The naked-eye study of meteors is quite a laborious task, but even a casual observer, watching for, say, ten minutes on an August night, may observe a number of Perseids. If their tracks are marked on a star map, and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers with their radiants; the effect of moonlight in 1975 is indicated.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	
Jan. 1-4	Quadrantids	Jan. 3	$15^h\,28^m$	$+50°$	
April 20-22	Lyrids	April 21	$18^h\,08^m$	$+32°$	
July 27-Aug. 17	Perseids	Aug. 12	$3^h\,04^m$	$+58°$	
Oct. 15-25	Orionids	Oct. 21	$6^h\,24^m$	$+15°$	M
Oct. 26-Nov. 16	Taurids	Nov. 8	$3^h\,44^m$	$+14°$	
Nov. 15-17	Leonids	Nov. 17	$10^h\,08^m$	$+22°$	M
Dec. 9-14	Geminids	Dec. 14	$7^h\,28^m$	$+32°$	
Dec. 17-24	Ursids	Dec. 22	$14^h\,28^m$	$+78°$	M

M=moonlight interferes

Minor Planets in 1975

Many thousands of minor planets (asteroids) are known, most of them having orbits which lie between those of Mars and Jupiter. More than 2,000 of these have been seen at more than one opposition and their orbits are sufficiently well determined for them to be given an official number in Minor Planet Catalogues. Some of the asteroids, however, can come within the orbit of Mars, and a small but important group is known whose members have perihelia well within the orbit of the Earth. The first of these to be discovered was named Apollo, and in 1932 it came within 7 million miles of the Earth. It was seen for only three weeks, and was then lost for forty years. One of the success stories of 1973 was the recovery of this planet as the result of extensive calculations by Dr Marsden, and a search by McCrosky and Shao of Harvard Observatory. The little planet, which is probably only about a mile in diameter, was found on 27 March 1973. It was not particularly close to the Earth on this occasion, but it will come much nearer in 1980 and 1982. It is now clear that Apollo must have passed less than a million miles from Venus in 1950. Apollo was the first known member of a group of asteroids which now numbers seventeen, and which includes such remarkable bodies as Icarus, which can pass well inside the orbit of Mercury; Geographos, which seems to have a curiously elongated shape; and Hermes, which came within half a million miles of the Earth in 1937, moving so quickly that it was only seen for five days.

Some of the minor planets are bright enough to be followed with a small telescope, but only the 'big four', Ceres, Pallas, Juno, and Vesta can reach any considerable brightness, and Vesta can occasionally be seen with the naked eye. In 1975 Vesta comes to opposition on 18 September, when it reaches magnitude +6·2. It should be easily visible in binoculars on the borders of Aquarius

and Cetus (see diagram, page 79; note, page 93). Pallas is at opposition three days later, but it is some degrees north on the borders of Aquarius and Pisces, and only reaches magnitude +8·5. Ceres is at opposition on 1 December, in Taurus near the star Aldebaran, but its magnitude is then only +6·8. There is no opposition of Juno during the year.

Some Events in 1976

ECLIPSES

In 1976 there will be three eclipses, two of the Sun and one of the Moon.

29 April – an annular eclipse of the Sun, visible in Asia, North Africa, and Europe.

13 May – a partial eclipse of the Moon, visible in Australasia, Asia, Europe, and Africa.

23 October – a total eclipse of the Sun, visible in Australia, Asia, and East Africa.

THE PLANETS

Mercury may be seen most easily as an evening star near eastern elongation on 28 April, and as a morning star at western elongation on 7 October.

Venus will not make a very outstanding display in 1976. It is a morning star for the first half of the year, and becomes an evening star after superior conjunction on 18 June.

Mars will be seen as an evening star for the greater part of the year, and is in conjunction with the Sun on 25 November.

Jupiter is in conjunction on 27 April and comes to opposition in Taurus on 18 November.

Saturn is at opposition in Cancer on 20 January, and in conjunction on 29 July.

Uranus is at opposition on 25 April on the borders of Virgo and Libra.

Neptune is at opposition in Scorpius on 3 June.

Pluto is at opposition on 30 March.

PART TWO

Article Section

Minor Planet 433 Eros

J. G. PORTER

In late January 1975 the minor planet Eros comes to opposition near its perihelion, and it is then at its closest to the Earth – about 14,000,000 miles. On the date of opposition the planet will be in Gemini, a few degrees south of the star Pollux, but the motion of Eros will carry it rapidly south. The predicted magnitude of the planet at this time is 8·7 (photographic), and although it may well be brighter than this visually it will not be visible to the naked eye. This close approach is interesting because the conditions in 1975 are almost exactly the same as those in 1931, when measurements of the position of Eros were the main object of one of those great co-operative campaigns conducted by an international team of astronomers. The similarity of the 1975 opposition to that of 1931 arises because the sidereal period of Eros is 1·76 years, and twenty-five such periods are equal to forty-four years.

The orbit of Eros is very well determined, regular observations having been made since its discovery on 13 August 1898 by Gustav Witt at the Urania Observatory, Berlin. Photographic discoveries of this kind had been made since 1891, when Max Wolf at Heidelberg had found the first trail of a minor planet on a photographic plate. In those days new planets were given a number as soon as they were discovered, together with a name. The names chosen were at first those of Greek goddesses, but the supply had run out long before 1891, and Wolf named his new discovery Brucia, in honour of Miss Catherine Bruce, a noted American patroness of astronomy, who had greatly helped Wolf in his work. The little planet discovered by Witt was number 433

and as soon as an orbit had been calculated, it was realized that this was quite an exceptional object, and its unusual character was emphasized by giving it the masculine name Eros. Nearly all of the minor planets have mean distances from the Sun between 2·1 and 3·1 astronomical units, so that they move in a fairly narrow belt between the orbits of Mars and Jupiter. Eros, however, has a mean distance of 1·458 a.u. and since its orbit is rather eccentric it can travel out to 1·783 a.u. at aphelion; but it can then cross the orbit of Mars to come to perihelion at a distance of 1·133 a.u., which brings it only 14,000,000 miles from the Earth's orbit. It was at once realized that such a close approach could lead to an improved value of the solar parallax, which for centuries had been taken as the fundamental unit of measurement in the solar system. The solar parallax is defined as the angle subtended by the Earth's equatorial radius at a distance of one astronomical unit, i.e., at the mean distance of the Earth from the Sun. The astronomer uses this angle to calculate the parallax of a planet or comet, but if the actual length of the Earth's radius is known, then the length of the astronomical unit in miles or kilometres is easily found.

Unfortunately the solar parallax is a very small angle – only a few seconds of arc. The ancient Greeks had a very hazy idea of the distance of the Sun, and their opinion that it was only 1200 times as far away as the Moon persisted well into the seventeenth century. Kepler was able to show that the solar parallax must be less than a minute of arc, but even in Halley's time a value somewhere between 9 sec. and 10 sec. was accepted. Halley suggested the method involving the rare transits of Venus, and extensive observations of the four transits in the eighteenth and nineteenth centuries were made, although the results were very uncertain because of the practical difficulties in timing the exact moments of ingress and egress of Venus on the solar disk. The discovery of Eros suggested that similar methods could be used at the close opposition of this planet. Thus, if Eros were observed at this year's close approach to be in the zenith at station A and on the horizon at station B, there would be a difference between the two apparent

positions of about 58 sec. due to parallax alone, and a quantity of this order is easily measured. Knowing the distance between the two stations, the solar parallax may easily be calculated. In practice, of course, the planet cannot be observed either in the exact zenith or on the horizon, but it can be photographed east and west of the meridian at any station, and the mathematics involved is not very different. This comparatively simple method was tried by Gill in 1877 on the island of Ascension, using the planet Mars, but here again difficulties were found in making the measurements owing to the colour of Mars and the size of its disk. Gill therefore decided to adopt a suggestion made by Galle in 1872 to use the minor planets for this work, because they have no particular colour and their images are star-like. (The minor planets are also called *asteroids* because of their stellar appearance.)

In 1879 the minor planets Victoria, Iris, and Sappho were observed at a number of stations widely spaced on the Earth. The calculations which followed were much more complicated, and it took ten years to produce a final value of 8″·80 for the solar parallax, a figure which is still in use in the almanacs and among observers. The method using the minor planets had obvious advantages, and when Eros was discovered, only a year after Gill had completed his calculations, it was realized that this planet would approach the Earth in 1901 within 30,000,000 miles – much closer than any of the planets previously used. So another joint effort among many observatories was made, and the result, published nine years later, fully confirmed the previous value. But there is always an urge to achieve greater accuracy in science, and an even more extensive effort was planned for the 1931 opposition, when Eros would be only 16,000,000 miles from us. This time an International Commission was chosen to make plans for the campaign, the circumstances being exceptionally favourable. At this opposition (as in 1975) Eros was not only near perihelion, but it was also close to its descending node. The orbit is inclined at about 11° to the ecliptic, and the planet at this time is moving at almost the same speed as the Earth. As a result, its movement southwards across the ecliptic is greatly exaggerated

by its closeness to us, so that the planet appears to make a huge sweep across the sky from high northern declinations right down into the southern sky. It could therefore be observed equally well in both hemispheres, and observatories all over the world were invited to co-operate. In all, forty-four observatories took part, obtaining nearly three thousand measurements of position, and the task of reducing all these results was in the hands of the late Sir Harold Spencer Jones at the Royal Observatory, Greenwich. The result, produced in 1941, gave a new value of the solar parallax of 8″·790, and the difference from the previous value caused some surprise and a great deal of discussion.

We need not go into all the arguments and conflicting opinions, but the 1931 result was never officially adopted, and the matter was only finally resolved when we entered the space-age, and new and powerful radar transmitters were used to measure astronomical distances with real accuracy. In 1961 and 1962 the distance of Venus was measured by radar when the planet was near inferior conjunction, and the resulting value of the solar parallax was adopted by the International Astronomical Union at its meeting in Hamburg in 1964. At this point the story takes an unexpected turn. In these days of space exploration the solar parallax no longer has its former importance as the primary unit of measurement of distance. What the modern astronaut needs to know is the actual distance between one planet and the next, and for this reason there has been a complete change of emphasis. The fundamental unit of today is the astronomical unit, and it is defined in terms of the metric system as 149,600 million metres. Space probes have also given us a better value for the equatorial radius of the Earth, which is now known to be 6,378,160 metres. From these two values we can now derive the solar parallax as 8″·79405. The extra decimal places have no value to the astronomer, but it is some comfort to the astronaut to know that his unit of distance is now known to six significant figures, that is to 1,000 kilometres.

If Eros has lost its importance in measuring distances, its close approach in 1975 will still be of much interest. A great deal of

work is in progress at the present time on the orbits of the asteroids, and on their constitution, shape, and size. The orbit of Eros is no longer outstanding, for since 1931 about thirty minor planets have been discovered which can come as close, or even closer to the Earth, and more than half of these – the Apollo group (see page 116) – can come inside the Earth's orbit. The record for a really close approach is still held by the little planet Hermes, which came within half a million miles of the Earth in 1937, but was only observed for five days and has not been seen since. This was an exceptional case, but the normal opposition of a minor planet gives an opportunity for optical studies which are slowly building up a better picture of the nature of these small bodies. Many of the asteroids show a marked variation in brightness, and Eros was found to behave in this way at the beginning of the century. It is some measure of the attention that this planet has received that more than a hundred light-curves of Eros have been made since its opposition in 1901. Measurements of the magnitude of the planet are plotted against the time, and the resulting light-curves show a variation of light amounting to more than one magnitude in a period of $5^h\ 16^m$, the curve showing two maxima and two minima in this period. This suggests that Eros is elongated in shape, roughly 15 miles long and 5 miles wide, and is spinning about its shorter axis. It is thus seen alternately end-on, giving a minimum, and broadside-on giving maximum light. Many other minor planets behave in the same way, and some of them seem to have different reflective powers on opposite sides.

There is a considerable range in the sizes of these bodies, from the 650-mile diameter of Ceres to the half-mile of Hermes, and the majority must be even smaller than this. This is hardly surprising, but it does give rise to speculations as to the origin of the minor planets. Were they originally formed as separate bodies, or have they resulted from the break-up of a major planet which once revolved in the space between Mars and Jupiter? The thousands of minor planets which we know today are all so small that they cannot retain an atmosphere, and they have probably remained unchanged since their formation in the remote past. If we could

learn something of the surface constitution of these planets we might have a clue to their nature and perhaps to the origin of the solar system itself. This is the aim of modern work, which not only uses light-curves but also includes measurements at many points in the infra-red spectrum, and estimates of the amount of polarised light which is reflected from the planet's surface. These facts can be used to give information on the nature of the surface, and comparison with similar measurements of meteorites which have fallen on the Earth will show if there is any connection between the two classes of body. Meteorites may have arisen from destructive collisions of asteroids, but although some similarities have been found, it is too early to make definite pronouncements on this subject. Perhaps, before too long, a space probe will be able to bring back some specimens of the surface material of a minor planet, and then we shall at least know some of the answers.

A Rotating Observatory

F. R. SPRY

Motor-cars and telescopes are not usually cheaply acquired. Cars, whenever possible, are garaged. Telescopes are not often so lucky. When the car is being used, you are inside it; with a telescope, you are outside it – and outside in the fresh air.

Being of an age when I put comfort before speed, protection from the chill winds was much to the fore in the design of the observatory I built for my 6½-inch Newtonian reflector. My aim was simplicity of construction, low cost (without sacrificing efficiency), total rotation if possible, ease of entry, and weather-proofing.

The chosen size has always to be a compromise between 'How large an observatory can I afford with regard to materials?' against 'How small can it be to allow for self and 'scope to work in comparative comfort, and also allow for the occasional visitor or two?' My Newtonian has a rather long focal length (65 inches) for its aperture, and the tube, an open skeleton made of wood, is over five feet long. For ease of construction I decided upon a square observatory, rotating on a steel ring. Seven feet square was deemed to be the minimum possible size: and for better or worse, I accepted it.

A nine-foot square base of concrete was the first prerequisite, with strips of 2 in. × 2 in. wood let in to finish flush with the surface. The idea of this was to have something to which the base could be secured if required, without having to drill any holes in the concrete. A four-inch hole was left in the centre for electric supply cables to come through. Wires trailing across the floor are highly dangerous, and can soon cause damage to life and limb

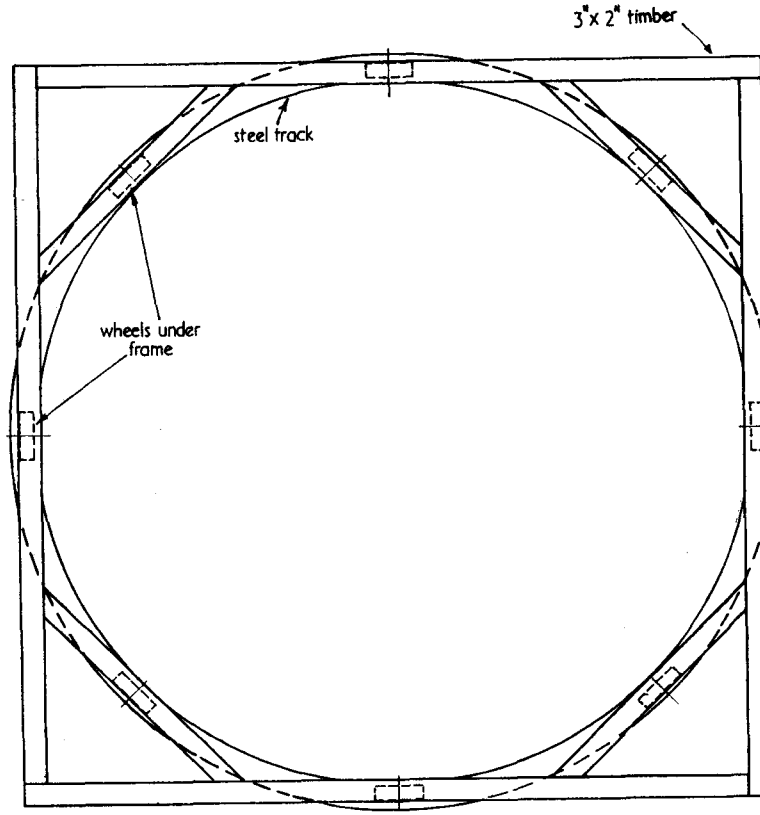


Fig. 1.

as well as to delicate optical components. I *had* intended to lay a piece of pipe for the cables under the concrete, but in the excitement of the moment I forgot it until too late. However, I managed to push a piece through by digging a shallow hole, so that the objective was eventually achieved. A little foresight can save a great deal of unnecessary labour!

I am fortunate in having a very efficient and co-operative blacksmith almost on my doorstep, which makes life much easier

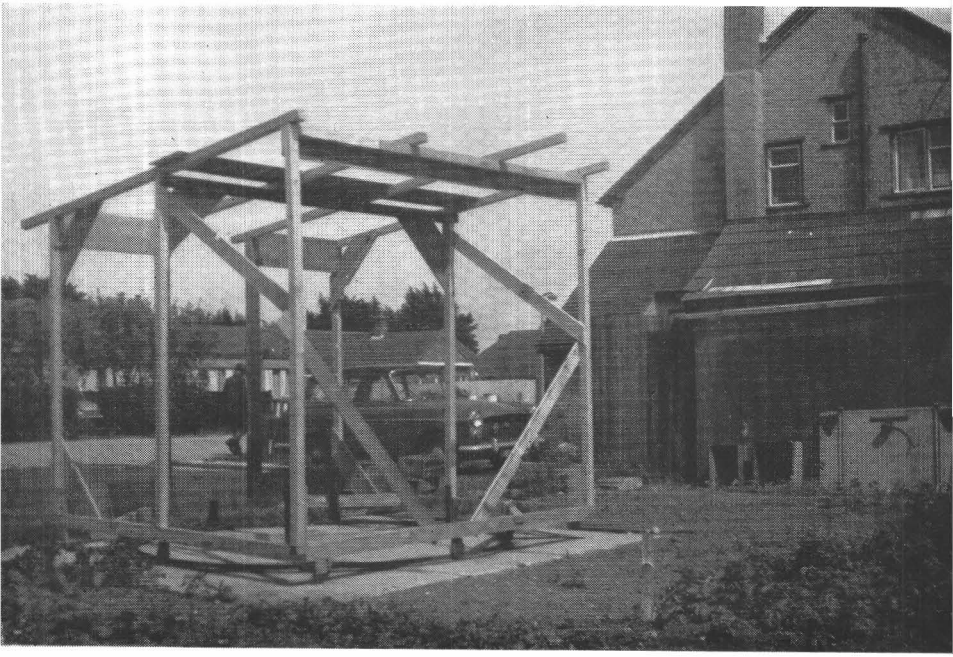


Fig. 2.

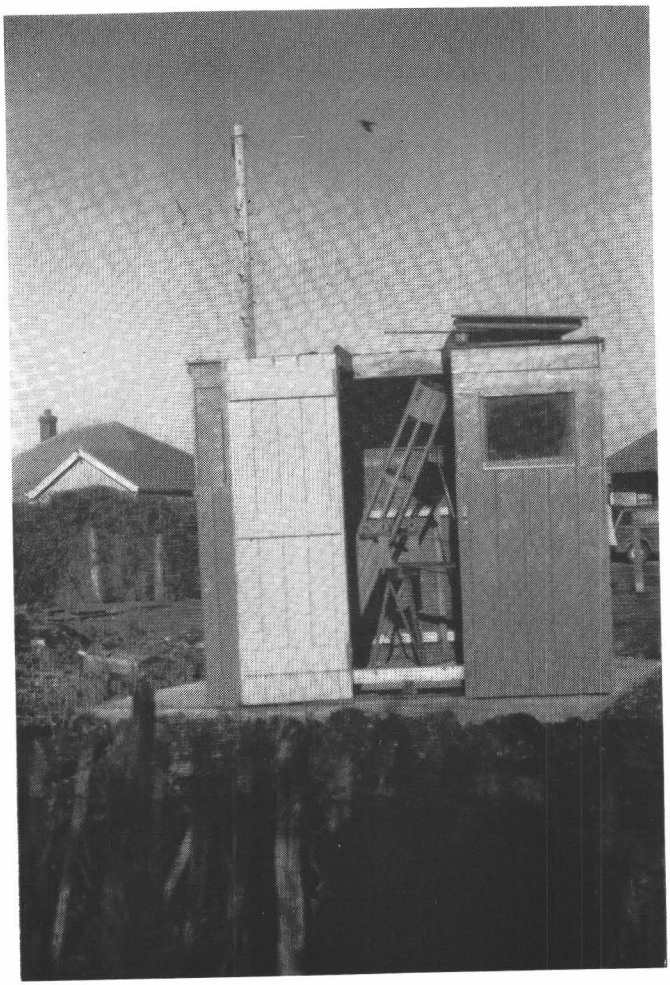


Fig. 3.

when things of this sort are to be constructed. He made a 7-foot diameter ring of L section for the wheels to run in, as shown in Figure 1. He also made *h*-section housings for the wheels, and the disks for the wheels from a piece of 3½-inch diameter bar cut into slices. To forge a ring of angle-iron in one piece is quite a job, so the smith suggested that it would be easier and cheaper to weld several sections that he could pre-fabricate more accurately in his bending machine. This was done, and has since proved most satisfactory.

I have a fairly well-equipped workshop with a Myford M.L.7 lathe, so that I can tackle most machining jobs. I also have access to a friend's 6-inch lathe if need be, and I used it; the wheels were turned true, and bored for the axles, on it. The base frame was made from new timber, 3 in. × 2 in. half-jointed and screwed. The inside diagonals formed an octagon, to which the eight wheels were secured. I suppose an outside shaped octagon would look more decorative, but it would mean much more work and would provide less room inside.

The *h*-section wheel-housings enabled the frame to be set firmly on them, and they were well screwed. Three of them had been made with longer heads to secure to the centre uprights for strength and stability. Brackets with small wheels were added to touch the side of the ring, to keep the frame central and the large wheels free-running.

A light door was obtained cheaply from an old building which was being pulled down locally. This was 2 ft. 6 in. wide by 6 ft. long. If you build an observatory and you have any choice in the matter, don't skimp on the door-width; one has to get apparatus in and out. The door-frame was first on the stand, followed by corner posts, other uprights and roof timbers. When I bought my house there was an elderly shed in the garden that had seen better days, and by careful dismantling there was enough sound timber to complete the observatory sides and roof. An opening was left in the roof, extending back just past the central line, in order to give the telescope the full 90 degrees of declination; it was covered by a hinged flap cover, as shown in the Figure 4.

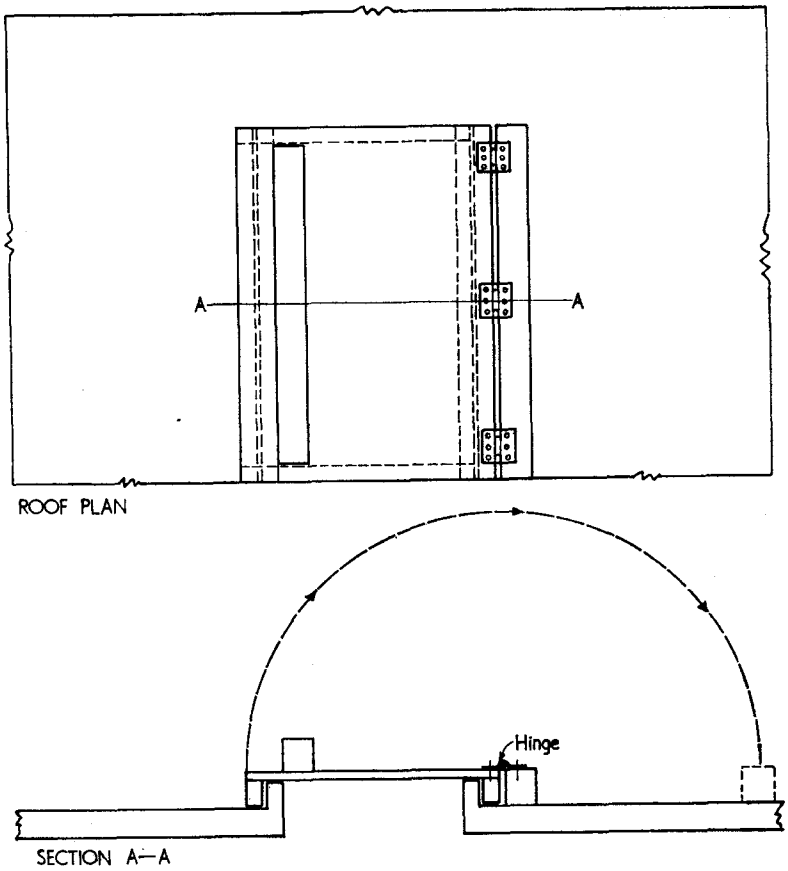


Fig. 4.

A length of half-inch steel rod attached to the underside of the flap enabled it to be pushed up until just over the point of balance, and gently lowered to lay on the roof. Recovery is, of course, by the reverse action.

Several observatories that I have seen have only the top part revolving, from about four feet up. Entry is effected by undignified ducking under the rail. I can walk upright into my observa-

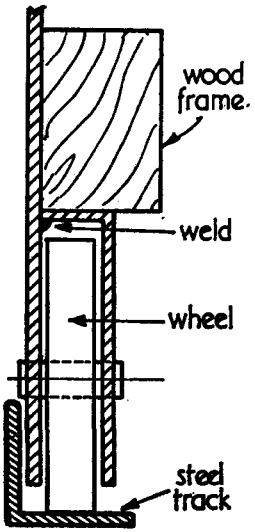

wood
frame
weld
wheel
steel
track

Fig. 5a.

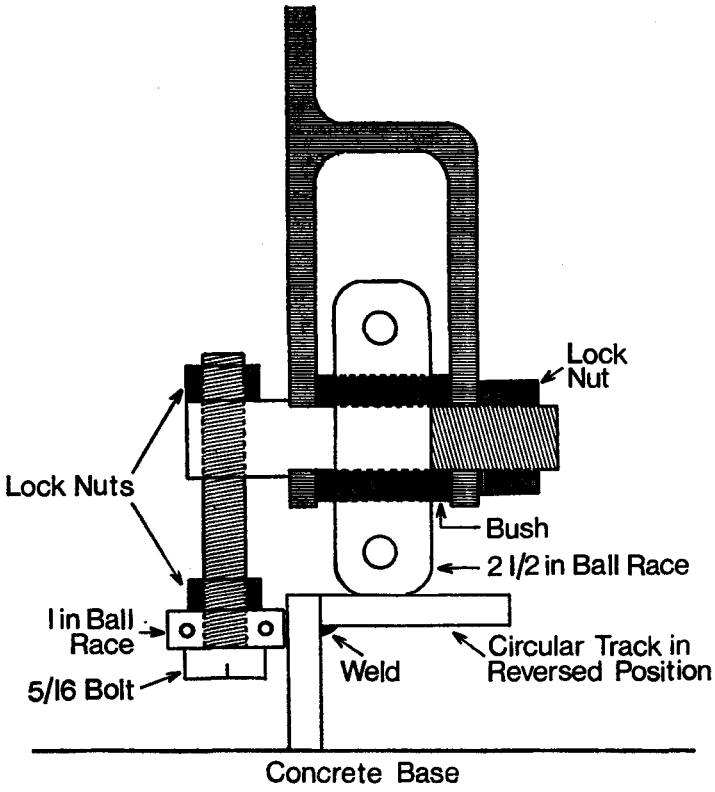

Lock
Nut
Lock Nuts
Bush
2 1/2 in Ball Race
1 in Ball
Race
5/16 Bolt
Weld
Circular Track in
Reversed Position
Concrete Base

Fig. 5b.

tory. To make the structure rigid as a result of this style of construction, I have it well braced with inside diagonals.

The roof was covered with ordinary roofing felt, well secured with battens screwed to the top and sides. I live at Selsey Bill in Sussex – and it can get breezy here, so guarding against the wind is high priority. The observatory recently stood up to a force-15 gale, which is a pretty good test! For an observatory of this sort, various materials can be used to keep out the wind and rain, always provided that the framework is sound. If well secured, use can be made of light plastic sheeting, hardboard, or weatherboard, for instance.

When the building was completed, the telescope was duly installed; and observing could be carried out in true comfort.

Everything worked well – except that the turning was not quite so easy as I had hoped, and on occasions there was need for forceful pushing. What could be done to improve matters? Ball-races, I thought, could be the answer. Unfortunately they are not cheap, and I needed eight, at least $1\frac{1}{2}$ inches in diameter or larger if possible, together with eight smaller ones as guides if the job were to be done properly. I was lucky in finding them – in fact I bought them for a modest £1; they had come from a local rubbish-tip where all sorts of things are dumped, and I knew someone who made a habit of visiting the tip regularly to see what could be usefully salvaged.

I made the new shafts and bushes in my workshop, but I now required the ring to be an inverted L with the flat on top and the sides on the inside. This meant lifting the observatory up; it had to be raised enough for me to pull the ring out, reverse it, and slide it back again. Using plenty of small blocks, 2 in. × 1 in., 2 in. × 2 in., 3 in. × 2 in. and so on, I levered up by going round and round an inch at a time, and it was soon where I wanted it. Out came the ring; it was reversed, replaced, and lowered on to the new rollers. Slight modifications, with various degrees of packing, were needed to get the right spacing; and I made a trial run. What a difference! It was fingertip control now, and the observatory just glided round. It still does.

Planetary Nebulæ

DAVID A. ALLEN

The brightest star in the sky, the sun apart, is magnitude $-1{\cdot}5$. There are galactic clusters as easy to see as second magnitude stars. The brightest gaseous nebula is an obvious naked-eye object, as is the brightest galaxy. Globular clusters reach magnitude 3. But the brightest planetary nebula is magnitude 7 – a factor of 50 fainter. Messier's catalogue contains only four of them: numbers 27, 57, 76, and 97. Planetary nebulæ are the least known and least observed of the so-called deep sky objects. Yet they are the most numerous. The *Catalogue of Galactic Planetary Nebulæ*, compiled by Perek and Kohoutek in 1967 (hereafter referred to as the CGPN), contains more than a thousand of them in our own galaxy alone, and since its publication several hundred more have been found. In this article I shall take the CGPN as a source list and examine the objects included in it. I shall ask of them what they have in common – what characteristics make them planetary nebulæ. In so doing I shall find many intruders, objects which have little in common with the rest. When I set out to ask the question 'What is a planetary nebula?', I shall fail to find an entirely satisfactory answer.

Discoveries

When Messier happened upon the Dumbbell Nebula, his first thought was not that he had discovered a planetary nebula. To him it was nothing more than another fuzzy patch all too easily confused with one of the comets he had set his heart on discovering. It was William Herschel who coined the term when he began

to examine more closely the different types of nebulous object his telescopes revealed. Herschel found quite a few of what we now call planetary nebulæ, and was struck by the similarity many of them showed to the sharp disks planets display, and in particular to the small green disk of Uranus. In his classification scheme for nebulæ he set aside a special class for them, class IV. Herschel's first catalogue of planetary nebulæ contained a large number of incorrect entries, most of them being accounted for by galaxies.

It is rather surprising that the term stuck. Many astronomers of the time must have felt that Herschel's planetary nebulæ were not a separate class at all and deserved no special treatment. However, the term did survive, and was further strengthened by John Herschel's discovery of many more of the same type of object during his observing periods in Cape Town.

It was the invention of the spectroscope that finally clinched it. When the light from a planetary nebula is passed through a prism or grating it does not produce a continuous band from red to violet, as does sunlight. Instead only a few bright spectral lines appear. Of all the nebulæ the Herschels and others had found, only the planetary nebulæ and certain of the gaseous nebulæ showed this sort of spectrum, and the latter could usually be distinguished by their irregular shape. Here, then, was the one common feature that linked the known planetary nebulæ, so that when Dreyer published the *New General Catalogue* he was able with considerable confidence to classify 67 of the entries as planetary (or annular), and of these, 57 are still accepted planetary nebulæ according to the CGPN. All but one of the remaining ten Dreyer qualified with a question mark.

The spectroscope not only could help to classify planetary nebulæ: it also provided a useful tool to aid in their discovery. Around the turn of the century a great number of planetary nebulæ were added to the lists by spectroscopic rather than visual searches. The nebulæ so found were generally smaller than those discovered by the visual observers but were no less bright. Many were smaller than 5″ arc in diameter and some could barely be distinguished from stars. These tiny but bright planetary

TABLE I

Some bright planetary nebulæ

Nebula	*Co-ordinates 1950* h m ° ′	*Constellation*	*Size* ″ *arc*	*Mag.* m	*Type*	*Discoverer*	*Notes*
NGC 246	00 44·6—12 09	Cet	273×224	8·5	III	W. Herschel	Very irregular structure.
NGC 1535	04 12·1—12 52	Eri	20×17	9·3	II	W. Herschel	
NGC 2392	07 26·2+21 01	Gem	47×43	9·0	III+IV	Lassell	The 'Eskimo' nebula. Double shell.
NGC 3132	10 04·9—40 11	Ant	84×53	8·2	IV	J. Herschel	
NGC 3242	10 22·4—18 23	Hya	40×35	8·6	III+IV	W. Herschel	
NGC 3918	11 47·8—56 54	Cen	13	8·4	II	J. Herschel	
NGC 5873	15 09·4—37 54	Lup	3	9·2	II	Copeland	
NGC 6210	16 42·5+23 53	Her	20×13	8·6	II	Struve	Σ5N
NGC 6543	17 58·8+66 38	Dra	23×18	7·8	III	W. Herschel	Helical structure.
NGC 6572	18 09·7+06 50	Oph	16×13	8·2	III	Struve	Σ6N
NGC 6720	18 51·7+32 58	Lyr	86×62	8·6	IV	Messier	M 57, the Ring Nebula.
BD+30°3639	19 32·8+30 25	Cyg	13×10	9·6	IV	Campbell	Campbell's hydrogen envelope star.
NGC 6826	19 43·4+50 24	Cyg	27×24	8·4	III	W. Herschel	The Blinking Nebula (the central star appears to wink in small telescopes).
NGC 6853	19 57·4+22 35	Vul	480×350	7·4	III	Messier	M 27, the Dumbbell. Classified planetary by Huggins.
IC 4997	20 17·9+16 35	Sge	1·5×1·2	11·0	I	Fleming	Forms a double with nearby star.
NGC 7009	21 01·4—11 34	Aqr	79×26	7·8	IV (VI)	W. Herschel	The Saturn Nebula. Double shell.
NGC 7293	22 27·0—21 06	Aqr	880×720	6·7	IV	Harding	Very large and faint. Classified planetary by Curtis.
NGC 7662	23 23·5+42 14	And	32×28	8·4	IV	W. Herschel	

nebulæ we now call *compact*. Most of the planetary nebulæ in the *Index Catalogues I* and *II* are of this type.

In the intervening years we have progressed but little in our methods of discovering planetary nebulæ. The photographic plate has replaced direct visual observation: many faint planetary nebulæ have been found on the photographs of the *Palomar Observatory Sky Survey*. The spectroscope has merely been modified: searches for planetary nebulæ are now conducted by placing large prisms in front of Schmidt cameras so that every star photographed is spread out into a tiny spectrum. This is referred to as an objective prism survey because earlier researchers used refracting telescopes instead of Schmidt cameras. Indeed, the telescope

TABLE II

The principal discoverers of planetary nebulæ

Discoverer	*Abbreviation*	*Method used*	*Number found*
Abell	A	photographs	77
Haro	H	spectra	112
Henize	He	spectra	142
Kohoutek	K	spectra and photographs	194
Minkowski	M	spectra	203
Thé	Th	spectra	50

with which the greatest number of planetary nebulæ has been discovered is a 10-inch refractor used by Minkowski in the 1930s to survey the northern sky and by Henize two decades later to explore the southern hemisphere. This instrument is now stationed at Cerro las Campanas, the Carnegie Southern Observatory in Chile.

Most planetary nebulæ found after the publication of the NGC and IC have been given designations according to the name of their discoverer. The usual practice is to abbreviate the discoverer's name and to follow it by a number usually given by him. If one author has published more than one list of discoveries, two numbers are employed. Thus Pe2-15 is the fifteenth object in Perek's second list of discoveries. The abbreviations for the

astronomers who have found the greatest numbers of planetary nebulæ are given in Table II.

Appearances

It is a gross simplification to say that planetary nebulæ look something like planets, show roughly circular images sometimes with central holes, and have sharply defined edges. For while many undoubtedly do conform to this stereotyped description, an equal number do not. Thirty-eight of the objects in the CGPN are NGC nebulæ that were not classified as planetary by Dreyer. One of these is M27, the Dumbbell Nebula. Dreyer was hesitant about classifying these mostly because they did not conform with the then accepted definition of a planetary nebula. Perek and Kohoutek, in compiling the CGPN, relied on both photographic and spectroscopic evidence when classifying these nebulæ as planetary.

In an attempt to bring some order into the system, Vorontsov–Velyaminov devised a classification scheme based on the photographic appearance of planetary nebulæ. His classes were as follows:

I unresolved on photographs; stellar or compact
II oval or circular, uniform brightness
III oval or circular, not uniform
IV annular
V irregular
VI peculiar.

Classes II to IV are the types recognized by the early visual observers, and some class I planetary nebulæ were found by the earliest spectroscopy. It is the addition of class V and particularly class VI which hints that the term planetary nebula may not define an entirely homogeneous set of objects.

Some of the differences between the various classes can be seen in Figure 1 (opp. p.146). These drawings are from sketches by the author whilst observing planetary nebulæ with the 100-inch

Hooker reflector on Mount Wilson or, for the southern objects, with 40-inch telescopes in Chile and South Africa. It is apparent from these drawings that classes I to IV define a distinct type of celestial object – that when we talk about planetary nebulæ we are referring to a particular natural phenomenon. It is equally clear that many of these objects in classes V and VI bear little morphological similarity to these planetary nebulæ, and are probably misclassified. Just what these imposters really are I will attempt to answer later.

Spectra

About 30 or 40 bright lines characterize the optical spectra of most planetary nebulæ. The strongest of these is nearly always the principal line of the Balmer series of hydrogen, Hα at 6563 Å. The remainder of the Balmer series can usually be traced until the lines merge together around number 20. Helium – the next most abundant element – is also present. In some nebulæ the brightest helium lines are of the neutral element, in others the helium has lost one electron and produces different spectral lines. The nebulæ containing ionized helium must be hotter than those in which the helium is neutral.

So far so good, but there the identifications stop. Some of the strongest emission lines in the spectra of planetary nebulæ could not be identified with the known lines of the known terrestrial elements. Because quantum theory predicted so well all the observed lines of elements and their ions, it seemed inconceivable that these lines in planetary nebulæ might be unknown and unpredicted transitions of terrestrial elements; they must therefore be produced by unknown elements. Thus the existence of a new element 'nebulium' was hypothesized by some astronomers. The principal lines of nebulium were at 5007 Å (N_1) and 4959 Å (N_2). Theoretical physicists were set the task of finding what sort of element they must postulate to produce transitions at these wavelengths.

What the theoreticians did, however, was to establish that quantum physics is more complicated than originally thought.

They found that under unusual circumstances different transitions can occur in some common elements. Spectral lines are produced when electrons cascade down through the atom in times of about one hundred millionth of a second. Sometimes, however, the electrons get caught up on a metastable level. We might think of these as broad, gently sloping shelves. It may take up to a second for an electron to roll off the shelf and carry on its journey. In the laboratory, atoms bump into one another thousands of times every second, and these collisions shake the electrons off their metastable shelves. But instead of emitting a photon of light, as they would if they fell off naturally, the electrons give their energy to the colliding atom, and no radiation is emitted. In the laboratory, therefore, such spectral lines are not observed, and they are called *forbidden transitions*. To distinguish them from normal spectral lines the parent ion is written in square brackets.

In planetary nebulæ, the gas densities are so much lower than in the laboratory that the electrons fall off their shelves naturally. The forbidden lines are therefore observed. The mysterious nebulium lines are quite simply explained as forbidden transitions of double ionized oxygen, [0 III]. Table III lists the most prominent forbidden lines in planetary nebula spectra.

In what we may call normal planetary nebulæ, the N_1 line of [0 III] is a little stronger than its neighbouring Balmer line Hβ, while the [N II] lines are a bit weaker than Hα. It is the three lines around 5000 Å - Hβ, N_1 and N_2 – which give planetary nebulæ their characteristic green colour. Our eyes are rather insensitive in the red where Hα and [N II] are strong. However, the dyes used in many colour films are more sensitive in the red than at 5000 Å, so in colour photographs planetary nebulæ may appear red. Black and white films differ in their sensitivity to different lines and also differ from the human eye. For this reason photographic magnitudes bear little relationship to how easily seen a planetary nebula is. The Messier planetary nebulæ M76 and M97 are examples: both are often stated to be twelfth magnitude, but are much easier to see than this number suggests.

Spectra are available of a rather small selection of the nebulæ

TABLE III

The brightest forbidden lines in planetary nebulæ

Ion	*Wavelength*	
[N II]	6548 Å	} pair around Hα
	6584	
[O I]	6300	} usually weak
	6364	
[O II]	3727	} not observed in dense nebulæ
	3729	
[O III]	5007	N_1
	4959	N_2
	4363	N_3 only present in dense nebulæ
[Ne III]	3869	
	3967	blended with the Balmer line Hε

in the CGPN. Of many we know only that Hα and/or [N II] are bright. This, in fact, is how most planetary nebulæ are found. The objective prism surveys select objects with bright Hα lines. This includes not only planetary nebulæ. Many B stars have Hα in emission because they have quite dense coronæ: they are then called Be stars, the 'e' signifying emission. Most O stars have Hα emission, and so do Wolf-Rayet stars. Young stars – variables of the T Tauri type which have only recently condensed from nebulæ and are still surrounded by clouds of gas and dust – often have very strong Hα emission. Novæ and supernovæ, some gaseous nebulæ (H II regions), some galaxies and even some very cool stars also display strong Hα emission. How then are we to distinguish the planetary nebulæ?

If a star has Hα in emission, this will be superimposed on its normal spectrum. An objective prism survey will reveal a continuous spectrum with Hα and perhaps some other emission lines superimposed. In a planetary nebula the continuum is essentially non-existent: we see *only* the emission lines. Thus to recognize a planetary nebula on an objective prism plate we have to do two things: first find the bright Hα line, then decide whether there is also a continuum underlying it. If there is a continuum, we can be sure the object is a star of some sort; if not we call it a planetary nebula. Most of the entries in the CGPN are there because

on somebody's objective prism plate they show an Hα line but with no visible continuum. Whether there really is a continuum which was just below the threshold of the plate we do not know.

This problem arose even in the NGC. We find several objects classed as planetary nebulæ which we now know not to be. NGC 7114 is an example – it is in fact the nova Q Cygni. Many of these misidentifications were rectified in the CGPN, but others have been introduced by recent surveys of fainter objects. The misidentification problem is most extreme for class I nebulæ which are, by definition, photographically indistinguishable from stars.

Central Stars

What is the source of the energy which powers planetary nebulæ? They are far too tenuous for nuclear burning to proceed, and the more esoteric energy sources, such as gravitational collapse, don't work either. Planetary nebulæ must be powered by stars. When we examine planetary nebulæ carefully we find them all to contain central stars. Sometimes the central star is very bright and easy to see; sometimes it is extremely faint. But it is always present.

It is in fact the ultraviolet radiation of the star that provides the required energy. The ultraviolet radiation is absorbed by electrons and converted into the spectral lines we see. Since the hotter a star is, the more ultraviolet it exhales, we deduce that the central stars of planetary nebulæ are very hot. Some of them are as hot as 100,000°K, 20 times the surface temperature of the Sun. In fact the central stars of planetary nebulæ are the hottest stars we know of with the exception of novæ and supernovæ during their brief hour of glory.

In order to begin to understand a star, we need to know not only its temperature but also its luminosity. To deduce the latter we must know its distance, and here we are at a distinct disadvantage. We just do not know how far away planetary nebulæ are. We can be certain that they are within our galaxy, and we also know that they are too distant for us to measure their parallax, but beyond that we can do no more than make inspired

guesses. In only one instance do we have a good estimate, and that is for Pease 1, a planetary nebula uniquely sited in the globular cluster M15. Using Pease 1 as a yardstick, we can estimate that most planetary nebulæ are several thousand light years distant, but we must exercise caution when theorizing about their nature and origin lest this estimate is a misleading one.

Origins

Even with no knowledge of the distance, we can draw some interesting conclusions from the distribution of planetary nebulæ on the sky. It is at once apparent that they cluster along the plane of the galaxy, and this tells us that they are not extragalactic. We see them in other galaxies too, in particular the Magellanic Clouds. Further, they concentrate towards the galactic centre rather than the spiral arms, and in this respect they mimic most closely the distribution of the cool M-type stars.

Why should the hottest and the coolest stars in the galaxy cluster together? The natural answer is that the two are somehow related, perhaps evolutionarily. The current theory is as follows:

A star like the Sun lives a quiet life for perhaps 5,000 million years, steadily burning its hydrogen into helium and giving off light as a result. A star is not very ecology-minded, however. One day it suddenly finds that its stock of hydrogen is running out. As extinction threatens, it changes its feeding habits and its girth to match. Now in its innards it gobbles helium, puffing its outer layers out to several hundred times its original radius. The Sun, for instance, will completely swallow all the inner planets when its turn comes. The spectral type changes from G to M and the star is now a supergiant.

So big does it get that it can no longer exert control over the goings-on at its boundaries. The atoms there are dashing around at something approaching the escape velocity, and as a result they smoke gently off into space. If conditions are right, most of the outer part of the star can be shed in a single puff, and this material expands to produce a gigantic bubble of gas. At the centre is the original star, now stripped of most of its flesh in this

celestial slimming campaign. Only the bare bones remain: the inner core of the star. The temperature of such a stellar core is very high, high enough to ionize the gaseous bubble. The star has become a planetary nebula.

Most planetary nebulæ appear darker in the middle, and some, like the Ring Nebula M57, have distinct central holes. This is because the material emitting the bright lines is concentrated towards the outer portions, which suggests that it was ejected by the star in one convulsion rather than a continual dribble. In some planetary nebulæ there are two concentric shells, suggesting two discrete ejection episodes. NGC 7009 in Figure 1 is the brightest of the double shell planetary nebulæ.

There is spectroscopic and other evidence to confirm that planetary nebulæ are expanding, as indeed they should be if the above theory is correct. In some cases the gas bubble has been distorted by bumping into a locally denser portion of the interstellar medium. In at least one case (NGC 7293) the planetary nebula finds itself expanding through a field of small dense globules of gas which stubbornly refuse to yield to the advancing bubble. The result is a pin-cushion effect in which the outer envelope of the planetary nebula is pierced by fingers of dark material all pointing accusingly towards the central star.

Because they expand, planetary nebulæ must start off very small – not much larger than stars in fact. Only later will middle-age spread make them resolvable to our telescopes. Planetary nebulæ of class I, the compact 'stellar' nebulæ, can arise from two distinct causes therefore. They can be young, or they can be very distant. If they are young we might expect the spectrum to be rather different. In particular, the gas should be denser because it has not expanded much since leaving the star. When the gas is dense we get different spectral lines enhanced; for example, the [O III] line at 4363 Å (see Table III). Indeed we do find that the densest nebulæ are of class I. The densest known planetary nebula is IC 4997 in Cygnus. This has about 10^8 atoms per cubic centimetre (whereas the air we breathe has more like 10^{20} atoms per c.c.). With large telescopes IC 4997 can be seen to be about 1″ arc

in diameter, but on photographs it appears entirely stellar. It has often been described as the brightest of the stellar planetary nebulæ by astronomers who never really look through telescopes.

A Planetary Nebula in Formation?

The theory of the origin of planetary nebulæ seems consistent with the available data. We have found young, dense, compact nebulæ and old, tenuous class II, III, and IV nebulæ. How nice it would be if we could find an M-type star turning into a young planetary nebula. Maybe we have.

In 1964 a faint Mira variable in Cygnus brightened in a few weeks by about a factor of 100. Previously not much was known about V1016 Cygni except that its spectral type was M. After the dramatic change spectra were taken. V1016 Cyg no longer resembled an M star – the spectrum was one of bright emission lines. It is not a normal planetary nebula spectrum in that the temperature is rather low, but with time it might develop into a perfectly conventional planetary nebula.

Intruders

We now have a fairly clear picture of a type of galactic nebula that we call planetary. We know what they look like: Vorontsov–Velyaminov's classes II, III, and IV, or if young or very distant class I. We know what sort of spectrum they have: lines of hydrogen and helium and the forbidden lines in Table III. And we think we know how they form and evolve. Let us now return to the CGPN and ask how many of its 1,000 plus entries are planetary nebulæ of the sort that we now understand.

I have already hinted that many of the class V and VI nebulæ may not be true planetary nebulæ and that some of the class I objects may be emission stars. I will now be more specific, and will deal first with the extended objects.

Supernova remnants

Many elementary textbooks refer to the Crab Nebula, M1, as a planetary nebula. It is not, and it is not included in the CGPN.

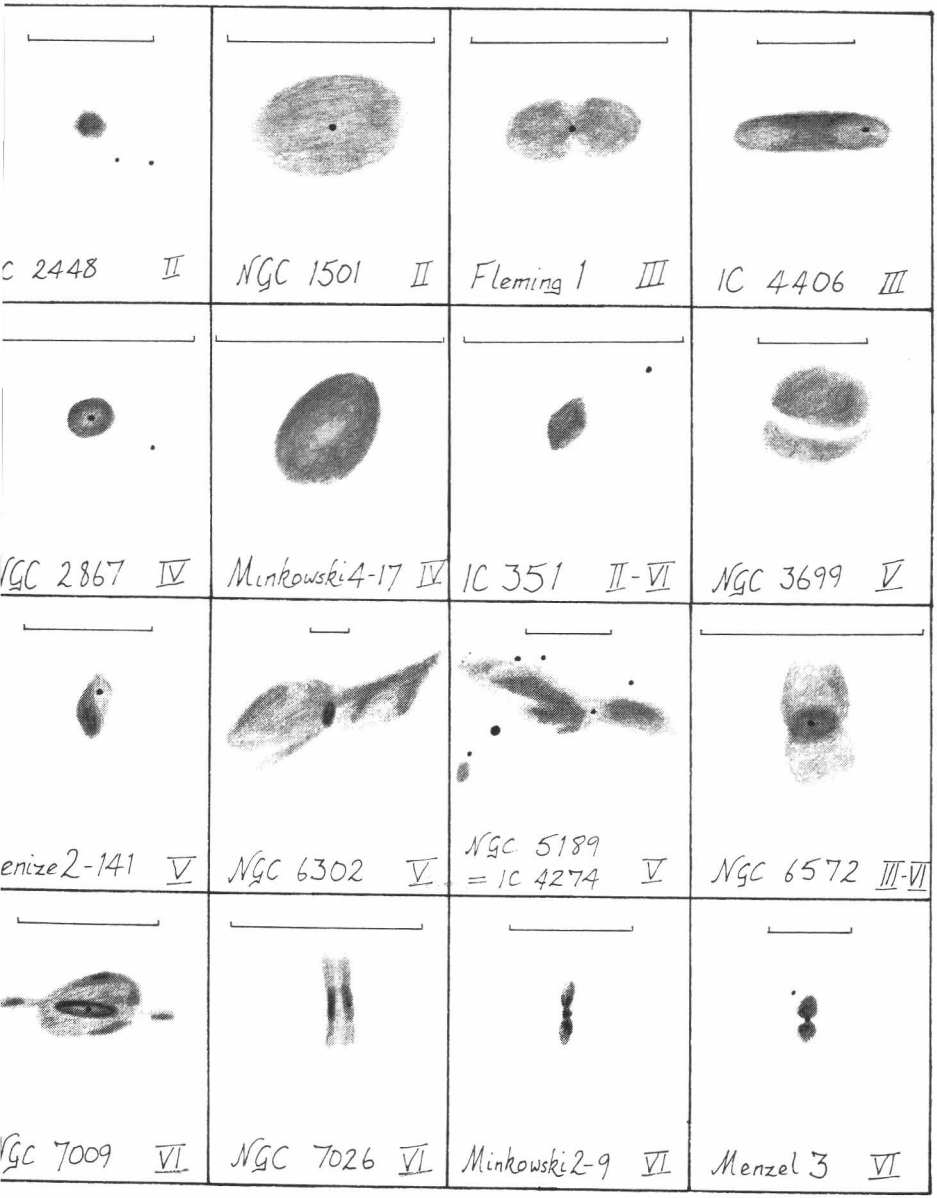


Fig. 1. A selection of planetary nebulæ: North is at the top; the horizontal line is 1′ arc in length.

The Crab Nebula is a supernova remnant – it has a totally different origin from planetary nebulæ, and its photographic appearance is quite distinct from that of any accepted planetary nebula.

Other supernova remnants are more regular than the Crab Nebula and, since they form by ejection of gas bubbles from stars, they can closely resemble planetary nebulæ. At least two of the faint nebulæ found by Abell on Palomar Sky Survey prints are supernova remnants.

Galaxies

Herschel's original list of planetary nebulæ contained many galaxies. These errors have all been corrected, but at least one galaxy was misclassified as a planetary nebula as late as 1967. This is the southern hemisphere object He2-10 which is an emission-line galaxy with a radial velocity of 970 km/sec. Other galaxies found by Jonckheere and classified as planetary nebulæ were rejected by Perek and Kohoutek in compiling the CGPN.

Gaseous Nebulæ

Some gaseous nebulæ are very similar to planetary nebulæ. They comprise a hot star surrounded by ionized gas. These are the H II regions, and they exhibit emission spectra very like those of planetary nebulæ. Their origin is very different, however, for while the planetary nebulæ are small shells of gas thrown off by stars in later life, H II regions are large clouds from which stars condense. And while planetary nebulæ are usually regular, H II regions tend to be irregular. Of course, there is a great range in degree of regularity in H II regions, and as a result it is sometimes difficult to distinguish the two. In compiling the CGPN, Perek and Kohoutek erred on the side of commission rather than omission. As a result their catalogue contains a number of objects which are almost certainly H II regions.

A group of objects called compact H II regions has recently been discovered. The characteristics of compact H II regions are small size, high density and large radio and infra-red flux. Some

are merely knots in large H II regions; others are spatially isolated and it is these which may be confused with planetary nebulæ. The job of eliminating the compact H II regions from the CGPN is still underway and it may be some time before it is completed. The best known compact H II regions in the CGPN are H2-3, H2-6, K3-50 and NGC 7027. Only the latter is visible in small telescopes; it was discovered by T. W. Webb and was classed as planetary in the NGC.

Peculiar Nebulæ

There are other objects which cannot be easily classified. They are certainly galactic nebulæ, but whether H II regions, planetary nebulæ or something else we cannot say. If some of them really are planetary nebulæ, then we must rethink our definitions drastically.

The problem quite simply is that no two celestial objects are really the same. Man, however, likes to put things in boxes, each with a clearly-written label. Life is complicated enough with reflection nebulæ, H II regions, compact H II regions, planetary nebulæ and supernova remnants. How much more complicated it is to introduce dozens more categories each comprising only one or two objects. Yet that seems to be the way it must be. Until we can clarify the situation, the simplest policy is to use the term *peculiar* as a general adjectival coverall.

Since the peculiar nebulæ are essentially individuals, it is not possible to describe them all here. Some are illustrated in Figure 1, and I leave it to the reader to decide from these drawings how he might classify the objects.

Two of the peculiar nebulæ I do want to describe, however. These are M2-9 and Mz 3 (Menzel), both in Figure 1. The two clearly form a pair because they are basically similar in shape and spectrum. The shape is distinctive: two exactly symmetrical jets projecting in opposite directions, each containing a selection of bright blobs and condensations. The boundaries of the wings are sharply defined, as though material is constrained there by a magnetic field.

The spectra are very odd. They resemble most the compact H II regions, but contain in addition a number of strong emission lines found usually only in stellar objects and in η Carinæ.

Finally they have much smaller radio fluxes than normal planetary nebulæ, yet are brighter in the infra-red than any other type of nebulæ.

Class I Planetary Nebulæ

The stellar planetary nebulæ were without exception so classified spectroscopically. As explained above, this may mean no more than that they have strong emission in the Hα line, and this definition allows many other objects to find their way into catalogues of planetary nebulæ. There are over 400 objects currently described as class I planetary nebulæ, and I estimate that half of these are not really planetary nebulæ at all. Most of the stellar planetary nebulæ are very faint and the labour involved in taking spectra of them to improve on the classification is vast. The intruders here are coming to light but slowly.

At least four of them are novæ that happened to be bright at the time of the relevant survey. These four are H2-9, Th3-22, Pe2-6 and Ap1-6 (Apriamasvili). M2-1 may also have been a nova since it certainly does not exist now. Vy1-3 (Vyssotsky) is a Wolf-Rayet star, M1-77 and M2-54 are Be stars and Bl3-11 (Blanco) is a star without even Hα emission! The Wolf-Rayet spectral classification scheme has recently been extended to encompass some rather similar stars, and two of these – M4-18 and He2-113 – were previously classed as planetary nebulæ.

About 40 class I planetary nebulæ seem to form a separate group more closely related to Be stars than to the M stars we believe to be the progenitors of conventional planetary nebulæ. It may be that some B stars throw off material in later life and thus come to resemble planetary nebulæ. They may even evolve into objects like M2-9 and Mz 3; at the moment we do not know.

Finally something like 100 class I objects are M-type stars. This result emerges not from spectroscopy but from infra-red photometry, for cool stars are very easily recognized by this

technique. Spectra have not yet been taken of most of them. While these M stars are certainly not true planetary nebulæ, we cannot help wondering if they are embarking on the road thereto. Are these perhaps the sort of object V1016 Cygni was before its eruption? Are these truly young planetary nebulæ?

What is a Planetary Nebula?

The contents of the CGPN form a heterogeneous selection of objects which cannot be simply classified. The majority of the objects probably do share a common nature and origin, and deserve the title of planetary nebulæ. Of the remainder we cannot be sure. Our definitions are imprecise because our understanding is too. Whether objects like M2-9 and Mz 3 are planetary nebulæ cannot be solved by semantical arguments, but only by determining their origin. This we may never do with certainty. Even the objects we confidently call planetary nebulæ may have originated in more than one way. And there will always be borderline cases – peculiar nebulæ or emission-line objects – which will be the subject of controversy as long as there are men to study them.

Mysteries of Quasar Redshifts

SIMON MITTON

We shall probably always look back on the past twenty years as an especially heroic age for astronomy. This period was marked by the opening of many new windows on the universe as new techniques developed by physicists and engineers came to be applied to experimental astronomy. An example which springs to mind immediately is that of radio astronomy; this science has developed from modest ambitions after World War II, to become one of the most important areas of modern astrophysics. More recently rocket engineers have thrown back the shrouds of our atmosphere, so that X-ray and gamma-ray measurements are now exerting an increasing influence on the advance of astronomy's furthest frontiers.

When a different view is possible in any branch of science, the practitioners can usually hope to come up with a few surprises. We have had a decade of astonishing progress in astronomy, as radio galaxies, quasars, the microwave background radiation, pulsars, X-ray sources, and most recently black holes have burst on the scene in quick succession. It would be unwise to expect that celestial exotica will be handed to us quite so freely in the future; we have penetrated the blanket of our atmosphere right through the electro-magnetic spectrum now, and any new classes of astronomical object are likely to be that much harder to find.

In a universe that contains so much which is new to us, one particular problem is proving unusually hard to solve: the nature of quasar redshifts. Quasars were discovered through the joint efforts of optical and radio astronomers in 1963; around ten years ago (1966) the truly great theoretical difficulties posed by these

objects began to emerge. Before outlining the nature of these difficulties, let us take a brief look at just what a quasar is.

Our story commences in the early 1960s, when astronomers were striving to identify the sources of radio emission which had by then been catalogued in their hundreds by radio telescopes. Although substantial numbers of these radio sources could be matched to optically visible galaxies, many discrete radio emitters did not have any galaxies in their vicinity. With the improvement of radio positions, however, the observers began to define more and more precisely the positions of radio sources in the sky, thus narrowing down the search area for optical astronomers. Soon there was a sneaking suspicion that at least a few of the radio objects coincided with unusual stars. A British scientist, Dr Cyril Hazard, decided to check this for object 3C 273 by use of the 64-metre radio dish at Parkes, in New South Wales. In order to derive a very accurate position for 3C 273 he monitored its radio signals as the Moon occulted it. Since the Moon's orbit through the sky is known with great precision, careful timing of the disappearance and re-appearance of the radio signal during an occultation can be used to pinpoint the area of radio emission precisely. When this was done there was no doubt that 3C 273 coincided with a starlike object, and not a galaxy.

Optical astronomer Maarten Schmidt, working at the Hale Observatories, decided to look closely at the 3C 273 'star'. He found a weird optical spectrum, which defied explanation immediately. Eventually, however, it became clear that the lines in the spectrum could be matched to the spectra of known elements if a redshift of 0·16 for all the lines were assumed. To be sure redshifts are familiar enough for the light from galaxies. In the 1920s Edwin Hubble showed that the redshift of light from a galaxy and its distance from us were simply related: the more distant a galaxy, the larger its redshift. At the present time it is generally believed that the recession speeds of galaxies are 20 km per second for every 1 million light years distance from us. On this scale, a redshift of 0·01 implies a speed of 3000 km/sec and a distance of 150 million light years. The redshift for 3C 273 im-

plies a speed and location characteristic of the farthest and faintest galaxies. This was the first example of a quasar. Loosely defined they are celestial bodies with a starlike appearance, high redshift, and powerful radio emission. If their redshifts obey Hubble's law they are the most powerful and remote sources of energy in our universe.

But do quasars obey the law of galactic redshifts? Within a few years of discovery this question began to cause much heart searching. Quasar redshifts of 2·0 soon became commonplace, implying recession speeds of four-fifths the velocity of light. Once velocities of this magnitude are interpreted in terms of Hubble's expansion law, enormous distances running in thousands of millions of light years result. But the very fact that we can see these objects in radio and optical telescopes implies that they must be truly colossal generators of power. In 1973 a record redshift of 3·53 turned up, meaning that spectral lines had been stretched out to 4·53 times the value that would be observed for the same substances in a laboratory of the Earth. If velocity alone is redshifting the lines, then the quasar is rocketing away at 92 per cent the speed of light. In such an extreme situation there would be something wrong if scientists did not question seriously the assumption that quasars are subject to the respected Hubble law.

Among the different notions which have been floated from time to time are the ideas that quasars may be curious bodies shot out of nearby galaxies at tremendous speeds, or that they may be extremely condensed objects with huge gravitational fields. Both of these hypotheses ascribe the giant redshift to something other than the expansion of the universe. But the difficulties with theories which set out to show that quasars are really on our own doorstep are twofold. On the one hand they lead to the conclusion that the total number of quasars in the universe would be extremely large, in which case the radio noise would be deafening, which is certainly untrue. On the other hand there are difficulties in devising viable models of super-condensed objects, and it is hard to find the requisite energy for expelling them from the local galaxies.

The simple observation that local theories are not really

satisfactory does not of itself prove that quasars must be cosmological (i.e. follow Hubble's relation). In fact a small number of independent thinkers have tried to demonstrate that the Hubble law is not all that it is cracked up to be. Halton Arp (Hale Observatories), for example, has published many papers in which he demonstrates that redshift and distance simply do not match for all galaxies. That peculiar collection of galaxies known as Stephan's Quintet has four member galaxies for which the redshift is eight times larger than is 'appropriate' for their apparent distance. In other cases Arp has pointed to galaxies which appear to be connected or associated, and therefore at the same distance one would suppose. However, he has sometimes found that the redshifts in a given association have different values. Geoffrey Burbidge has claimed that some quasars are suspiciously close to galaxies that have much lower redshifts than the quasar. Most astronomers have remained intrigued, but sceptical, when presented with this anti-Hubble evidence which hinges mainly on arguments that certain juxtapositions of celestial bodies cannot have happened through chance alignments. The value of the work of the dissidents is that it helps to keep an open mind on these matters.

The majority of astronomers have come down in favour of a view that quasar redshifts are cosmological. They argue that this assumption works very well for ordinary galaxies, and that any other notion will involve radical re-thinking, plus the overthrow of much theoretical work which has proved fruitful until now. One of the many obstacles encountered when trying to break out of the maze of conflicting facts is the lack of a really large sample of quasars that have been carefully studied. Many investigators have looked at the quasars which are listed in the 3C catalogue; however, this catalogue is biased towards sources that are strong emitters of radio waves, and they are frequently bright optical objects as well. Is it wise to assume that the most powerful examples of the quasar phenomenon are prepared to tell us the vital facts which will lead to a resolution of the problem?

Two or three years ago a small group of astronomers working in several countries decided to make a concerted attack on the

quasar problem. Their philosophy was that no single observatory would possess the full range of instruments necessary for a resolution of the issue, and so international collaboration would be required. The man primarily responsible for bringing together the quasar investigation team was Dr Cyril Hazard. He and his colleagues hope that they have now got within striking distance of answering one of astronomy's challenging problems.

Starting point of the international quasar hunt is the Molonglo Observatory in New South Wales. Radio astronomers there are engaged in making a survey of the radio sky that lists many thousands of radio emitters along with accurate positions. Precision in the location of the radio sources is the keynote to success, as searches for related optical objects become hopelessly protracted unless the search area is narrowed to a few seconds of arc. The primary data on locations are then used in conjunction with the famous Palomar Sky Survey in order to detect promising candidates for the optical counterparts of the radio sources. Much of this work has been undertaken at the Institute of Astronomy in Cambridge. Those cases where an interesting optical object coincides with a radio position are noted down for further detective work on large optical telescopes. The Steward Observatory, Arizona, along with the Hale and Lick Observatories in California have undertaken the detailed optical research on some of the more fascinating quasars which have been found as a result of the international programme.

The first shake-up came early in 1973 when it was announced that two quasars with record redshifts had been found: OH 471 has a redshift of 3·4 and OQ 172 a redshift of 3·53. These two objects are of importance no matter how the redshifts actually arise, since such high values must indicate extreme members of the quasar confraternity. Indeed before redshifts exceeding 3·0 had been discovered it was commonplace to assume that they gradually faded out at redshifts exceeding about 2·5: either such objects did not exist at all, of if they did they were too far away to see with the present breed of telescopes. The very existence of OH 471 and OQ 172 shatters the illusion that some mysterious astrono-

mical or instrumental barrier to really impressive redshifts exists. Consider the implications for experimental cosmology if we believe that this duo of quasars obeys Hubble's law. They are the most remote and most luminous concentrations of matter known to mankind. Also they are shining in a far-off region of the universe where the basic background temperature and the mean density of matter are much higher than in the highly evolved part of the universe in which our own Galaxy lives. If you prefer not to ascribe the redshift to Hubble's law, then an equally challenging piece of theorizing must be done. Has some colossal force or explosion accelerated the quasars to 90 per cent the speed of light? Or is some very radical new physical mechanism stretching out the spectral lines? Whatever the beliefs of individual astronomers may be, OH 471 and OQ 172 have something to offer.

Another far-reaching clutch of discoveries from the quasar hunt is that of several examples of discrepant redshifts. These are cases where the observed shifting in the spectral lines appears inconsistent with the standard cosmological interpretation for one reason or another. After an initial sifting for quasar suspects in the Molonglo radio catalogues, a suspected double quasar and three examples of quasars near to clusters of faint galaxies were noted. Observations of these associations started immediately in view of their potential importance to the astrophysics of quasars.

Radio source 4C 11·50 is visually a close pair of blue objects which look superficially like stars; they are separated on the sky by only five seconds of arc. A spectroscopic study of the two objects at the Lick Observatory came up with the amazing result that both objects are quasars! Very near to the pair of quasars are some extremely faint fuzzy objects which almost certainly represent the brightest members of a remote cluster of galaxies. The radio source which led to the discovery of the quasar pair coincides with the brighter member of the pair. Of this discovery Margaret Burbidge has said 'such a configuration is highly suggestive of a physical association'. That being so, we would 'expect' on a conventional argument, that both objects have the same, or nearly the same, redshift. But not a bit of it: the brighter member

possesses a shift of 0·44, and the fainter one a shift of 1·90. Curiously enough these values represent an interesting near-coincidence in that the wavelengths in the fainter object are almost twice as long as those in the bright quasar, since wavelength depends on (1 + z), where z is the redshift. The many coincidences noted during the investigation of 4C 11·50 seem to be either an unfortunate conjunction of chance elements or a profound mystery.

Another interesting discovery concerns quasars that appear to be grouped with galaxies. Several astronomers have looked for faint groups of galaxies near to quasars with low redshift. The argument goes that if you can find a knot of galaxies near a quasar, and then both galaxy and quasar redshifts have the same magnitude, then quasar redshifts must be cosmological. Already there are a handful of cases where the redshift of a quasar does not disagree with the values derived for nearby galaxies. But this does not settle the argument. First of all, the quasar-galaxy associations investigated up until 1973 had been selected in such a way that discrepant cases were likely to be excluded from the start. Secondly, the experiment had only been tried for quasars with low redshift, so nothing very positive had emerged for the redshifts exceeding about 1·0.

Cyril Hazard and his co-workers have found other quasar-galaxy associations where the redshifts are discrepant. Their investigation has been made in such a way that it is not biased towards finding cases where all the redshifts agree. Work at the Lick and Hale Observatories has come up with the following information on quasar-galaxy associations. Quasar 4C 24·23 is a blue compact object nestling at the edge of a neat cluster of five galaxies. These five smudges may be the brightest members of a remote cluster of galaxies stretching over two seconds of arc. Confirmation that 4C 24·23 is a genuine quasar comes from its spectrum which had a redshift of 1·27.

In another case a faint galaxy cluster surrounds quasar 4C 11·45, for which the redshift is 2·17. Then again, consider 4C 26·48; here a compact object whose redshift is 0·78 is within 10 seconds

of arc of a faint galaxy which could be the brightest member of a cluster. The three foregoing cases of quasars suspiciously close to galaxies have had radio positions very accurately measured in Cambridge and Westerbork, and there can be no significant doubt that the quasars have been correctly located.

Although none of the galaxies has had the redshift measured at time of writing, they cannot in any case exceed about 0·4. Once a galaxy is any further away than the distance corresponding to this redshift it simply cannot be seen with even the largest telescopes. For each of the quasars above the redshift is much more than 0·4. We therefore have a choice: either these three cases are chance alignments of far-off quasars with nearer galaxy clusters; or the Hubble law is violated by quasars, and the quasars and galaxies are all at the same distance. It is well known to astronomers that statistical arguments, based upon the chance of this or that particular alignment occurring by chance, are treacherously misleading, so these examples of discrepant redshifts do nothing to prove, in a scientific sense, what quasars are or show how far away they are. Nonetheless, such observations increase the suspicions that the simpler interpretations may be wrong, and they inspire quasar researchers to look for further examples, and thus try to get to the bottom of the great quasar mystery.

However, we can hope that the solution to these mysteries is at last in sight. The science of radio astronomy has now reached the stage where radio locations can be specified with great precision thus aiding the identification work for fainter objects. This step forward greatly increases the number of quasi-stellar objects available for study. The world's large optical telescopes now have a host of modern aids – image tubes, spectrum analysers, and on-line computers – that ease the task of studying very faint objects. The case for non-cosmological redshifts in quasars appears to be strong at present; in another few years we may have the final answer – or at least be as near to the final answer as you can ever get in astronomy!

The Problems of School Astronomy

E. A. BEET

When the Editor invited me to contribute on school astronomy I was very doubtful about accepting, first because he and I do not see eye to eye on the matter, and secondly so much has been written about it in recent years that there is nothing more to be said. However, I decided that Mr Moore and I have known each other long enough to differ amicably, and this publication may reach a different readership from the others. Let us begin by noting some of the other articles which have appeared. An historical review has been given by the present writer (*Journal B.A.A.*, *83*, 112, 1973); a study mainly of the present situation in schools and colleges by A. W. Lintern-Ball (*Quarterly Journal R.A.S.*, *13*, 486, 1972); the astronomical activities of the Inner London Education Authority by P. Richards-Jones (*Journal B.A.A.*, *81*, 135, 1971); the problems of the G.C.E. examination, also by Richards-Jones (*Physics Education*, *3*, 35, 1968). In 1973 *Physics Education* devoted a whole number to educational astronomy (vol. 8, no. 7): here will be found articles on the general problems of school astronomy, sixth form work, radio astronomy, telescope making, an educational planetarium, a municipal observatory, and a number of other topics of interest. The Department of Education and Science has also entered the field with a small book *Learning about space* (H.M.S.O., 1969) ,and no doubt in the interval between writing these words and the sale of the *Yearbook* something else will have appeared. What I say now, therefore, cannot be regarded as new.

A professional astronomer does not necessarily have to have a formal education in astronomy, as a good degree in physics or

mathematics is an adequate qualification for one who has a genuine interest in astronomy as well. A young man or woman, however, who feels that a degree course in astronomy is desirable can find one by choosing the right university. As well as from the U.C.C.A. *Handbook* information can be obtained on this from a recent B.A.A. publication *Careers in Astronomy*. It is not at this level that problems arise, so it will be discussed no further; the controversy is about whether and what to do in schools with average boys and girls.

Children (age in single figures) and young people are undoubtedly interested in things astronomical and always have been. The interest is often superficial and often short lived, but it is there and should be harnessed for educational purposes. The 'environment' for some people means pavements, street lamps, diesel smell, and a Sun or Moon shining dismally through the (mercifully getting less) polluted atmosphere. For others it means trees, flowers, birds – and stars. The first three have always been educationally recognized; why not the fourth? The heavenly bodies do form a part of the environment and should be accepted as such. Apart from that, astronomical topics are fired at us week by week by the modern media. As I write Comet Kohoutek has been in and out of the newspapers and popping out of the radio. Not long ago it was Pioneer 10 and Jupiter. Almost inevitably 'Mummy. What is a comootek?' Astronomy is a part of general knowledge. In school there has long been a subject 'general science', and we now hear of 'integrated science' and 'environmental studies'. Here is a place for some astronomical teaching, and indeed the subject has been available in some O-level general science papers for over thirty years, though little utilized. Whether astronomy is regarded in environmental or general knowledge terms, it ought not to be ignored at school age.

It would be unrealistic to expect astronomy to be a full school subject, except perhaps for selected seniors in a secondary school. The mixed science courses known under their various names provide the best niche for astronomical topics, though it can be successfully worked in with physics, mathematics or geography.

Where the teacher is an amateur astronomer it is almost certain that the 'working in' has happened, and the real problem is in schools where none of the staff is interested. Here I think it is better to leave it alone, so the advancement of astronomy teaching will depend on interesting and training teachers, both new recruits and in-service men and women. Something is being done about this, but so far is only scratching the edge of the problem as the number of individuals involved is only a small proportion of the whole potential or existing teacher force. Astronomy, and geology too, should have a place in the regular science lectures provided in teacher training colleges. Once the interest can be aroused it does not matter very much (in my opinion) whether there has or has not been formal training in astronomy, though of course it helps. Teachers of the subjects mentioned in this paragraph have the right background and attitude of mind to take up astronomy *if they really want to.*

Another problem that one hears from time to time is the lack of suitable equipment, visual aids, textbooks, and so on. Here I stick my neck right out and say 'fiddlesticks!' There is plenty of material about, and if a teacher cannot find exactly what he wants he can improvise, not throw in his hand. I taught physical science, in which of course astronomy had been 'worked in', for over forty years and belong to what is called (with respect by some and a sneer by others) the age of sealing wax and string. We had apparatus of course, and some of it was very good, but in nothing like the quantity provided now and we often had to make do. Many times I found that the bits and pieces assembled by the teacher with his own hands, and perhaps pupils' hands too, had a greater impact on the class than the shining commercial article out of the cupboard. Can it be that the 'unacceptable face' of the affluent society has spread to our boys and girls – wanting too much. I am, of course, no longer directly involved with schools, but I am told that children will not look at filmstrips unless they are in colour, and some contributions in this field which I have seen are lurid to extreme. I recently used, in a teachers' course, the Helios Planetarium. It is an admirable piece of equipment and

I can recommend it, but I still feel that it is not really necessary, for a lot can be done with a lamp and some balls of various sizes. Let us have new equipment by all means; it is very welcome, but we must not allow ourselves to become dependent on it. Of books there is no end. The B.A.A. maintains lists of suitable books and visual aids, and finds it very difficult to keep them up to date. I admit that there are rather few books specially intended for the classroom, as publishers find that they cannot command the mass sales needed to keep the prices within the limits of the school purse. On the other hand there are teachers who feel that the availability of books should be limited, or some pupils will use those instead of their own brains and activities.

Now we must consider the question 'What kind of astronomy do we teach, ancient or modern?' If the neck has not already been severed in the last paragraph I stick it out again, for if there must be a straight choice between the two my answer is 'ancient'. I am not thinking here of the A-level physics and mathematics students, but lower down the educational ladder, say the 9-14 age group, and in any case the choice is not really limited to the two words used. At the younger end astronomy must be introduced through phenomena which the youngsters can see for themselves, just as men of long ago could see them. I shall consider a course in three stages. *Stage 1* would form the main work at junior school level, with stage 2 touched upon. *Stage 2* would be the main part at secondary school, but an outline or refresher of stage 1 would have to come first. *Stage 3* applies to the élite near the top of the school. Passing through the series would be a transition from ancient to modern.

Stage 1 would include the constellations, the ancient figures and their stories; the Pole Star and apparent motions of the heavens, not necessarily fully explained; planets as moving objects in the sky; the Moon with its changing face and position. Pupils' questions about the Moon and planets will inevitably cause some overlap with stage 2, which will itself overlap with 1. Any course must include the constellations, but with this next age group the figures and stories are less necessary, though a more detailed

explanation of the diurnal and annual changes in the sky is required. So too is the study of planetary motions, including the Copernicus–Newton period of history and some simple mathematical considerations. In this stage there will be some study of the physical state of the celestial bodies and the class will finish at what I will call 'general science level'. In stage 3 there are alternatives. It could be the O-level examination conducted by the London Board, or the sixth form could turn its attention to modern and more speculative aspects such as the rival theories of cosmology, pulsars, and black holes. The children of stage 1 will bring in space travel on their own and it could well be allowed to wander as their interests lead. Young people of the later stages should be guided into the purely astronomical aspects, though in stage 3 there could be a wider study of astronautics as an alternative to one term of astronomy. A visit to a planetarium is desirable at any stage, and if it is an educational one such as I.L.E.A. at Wandsworth or the National Maritime Museum at Greenwich it will be possible to have a programme suited to the age group.

Probably the biggest problem is that of practical work, particularly as at present the educational pendulum is right over on the 'make him find out for himself' side as distinct from the didactic. Suggestions for activity in the classroom or laboratory have been published from time to time, and there is now a kit of material available commercially for teachers unable or unwilling to make their own. Classroom activities are both necessary and useful, but astronomy cannot be meaningful without direct experience of at least some of the topics being considered. Indeed the O-level examination demands attested records of three mainly observational projects. As with classroom work, various lists of outdoor exercises have been published. Weather is an obvious hazard, but there are others, illustrated by looking at four imaginary but typical schools. First the boarding school in the country. Excellent; opportunities can be made when teacher and pupils can gather after dark under an unobstructed sky. Now a local day school in a large village or small town. The majority of

the boys and girls live within walking distance of the school and can return after tea to gather round the school telescope with their teacher. Then the rural secondary school serving a large catchment area: soon after the end of afternoon school a fleet of buses has scattered most of its population over an area anything up to twenty miles across. The sky can still be seen, but observation is limited to simple projects that can be attempted at home. Lastly the important school in a large town. A few pupils may live nearby, but a great many will be out in the suburbs and will need transport to get back in the evening. When they do get back city lighting will have obliterated all but the brightest stars, limiting their work to the Moon and planets, and the Sun earlier in the day. Even those bodies may be obscured by neighbouring buildings. In spite of these handicaps, with determination something can be done, and in quite a number of schools is being done, on the practical side.

Children associate astronomy with telescopes, so there ought to be one, but it need not be large or elaborate. A two-inch refractor is useful provided that it is firmly mounted. A three-inch is better; it is readily portable and will do all that is necessary in stages 1 and 2. Anything larger calls for an observatory. School astronomical societies sometimes make reflectors of six-inch and upwards, and even build the observatory to put it in. On school observatories in general one can say that it is not really necessary, and for class teaching not very useful. On the other hand it is nice to have for stage 3 or the astronomical society, and a few schools have well-equipped establishments where more advanced work, such as spectroscopy and the measurement of double stars, can be undertaken. The observatory must, however, be recognized by the governors and headmaster as being just as much a part of the school premises as the laboratory or gymnasium. Otherwise this sequence occurs: astronomy master leaves – boys carry on, keeping observatory to themselves – those boys leave – observatory unused – roof begins to leak – steel bearings begin to rust – somebody 'borrows' the eyepieces. At this point there are alternative sequences. Either astronomically minded new master

discovers it – restoration; or new bursar arrives – 'clear away that old hut so that visiting cricketers can park their cars there'.

One other difficulty, already mentioned, that the astronomy master must face is that of the weather, and to this there is no answer. The practical astronomer has many disappointments; at least half of what he wants to do is clouded out. Amateur astronomers themselves have unlimited patience and perseverance, but young people have little of the former and varying endowments of the latter. It is difficult to maintain interest if week after week observing plans are frustrated, and here lies the necessity of having a good supply of things to do indoors – problems to solve and models to make.

Many schools (meaning numerically, not as a percentage of the total) are being active in astronomy and are doing good work both as a subject and as a hobby, but there are these special problems peculiar to it. Enthusiasts for the promotion of astronomy in schools must understand that realization is not as easy as it sounds. Nevertheless it is worth working for, and both the R.A.S. and the B.A.A. are doing what they can to help, each having a special Education Committee. The International Astronomical Union too is taking an interest and it is a part of the activities of its commission on 'The Teaching of Astronomy'.

Unravelling Jupiter's Secrets

H. G. MILES

Because of the great success of the lunar probes and those that have visited the neighbouring planets Venus and Mars, the success of the first Jupiter probe has been taken as a matter of course and has not created very much general interest. This is grossly unfair because the achievements of *Pioneer 10* warrant, from both a scientific and technological point of view, a premier place in the annals of the history of space exploration.

Jupiter has been under close observation for a considerable time by amateur observers and only recently have the professional physicists and astronomers taken more than a passing interest. Such names as T. E. R. Philips, B. M. Peek and A. F. O'D. Alexander, all past Directors of the British Astronomical Association's Jupiter Section, appear prominently in the story of the unravelling of the mysteries of the giant planet. The prominent belt formations visible more or less in any telescope, and in particular the Great Red Spot, have been of particular interest to the fluid dynamicist during the last 25 years. General interest in Jupiter, however, was given an impetus when it was discovered that the planet emitted radio waves. Various mechanisms were put forward to explain this but none was universally accepted. The possibility of sending space probes to the planet has widened the horizon of interested parties to the space scientist in general. At the Lunar and Planetary Observatory at Tucson, Arizona, much effort has been put into trying to interpret the behaviour of surface features logged so carefully over the last century. The importance of the amateur in this work can be indicated by the fact that recently the present Director of the B.A.A.'s Jupiter Section, W. E. Fox, was invited to Tucson to help in this work.

There are, however, many aspects that cannot be studied from Earth-based observations. One is the examination of the atmosphere in areas near to the terminator, i.e. the position of local sunrise and sunset. Photographs of the surface in general from space probes should provide far greater resolution, thus giving more information on the structure of the belts and zones. From the experience gained in sending probes to Mars and Venus, the usefulness of Jupiter probes is beyond question and the main limitations are centred on technological difficulties such as the reliability of equipment in a hostile environment for very long periods of time and the ability to converse with the probe at such vast distances.

The main purpose of *Pioneer 10* was therefore the testing of the ability of a system to survive these interplanetary conditions and the ability to send information over extreme distances.

The astronomical aspects could be considered a bonus if the systems were successful. Before reaching the vicinity of Jupiter the probe had to pass through the Minor Planet belt with its unknown hazards. No probe had so far successfully penetrated into and passed through this zone. The fact that *Pioneer 10* passed successfully through this region, reached the planet and successfully transmitted information back to Earth shows that, apart from minor snags, development of long range probes is being successfully achieved.

The flight to Jupiter began on 2 March 1972, and after a journey lasting 21 months and covering over 1,200 million km, the probe successfully passed the planet at a distance of 2·86 Jupiter radii at 02·25 on 4 December 1973. (The equatorial radius of Jupiter is 71,600 km.) At that time the planet was so far away from the Earth that the signals, travelling at the speed of light, 300,000 km per sec. took over 45 minutes to cover the distance. Clearly the success of the whole project depended on the accuracy of the trajectory achieved and results have shown that an exceptionally high degree of accuracy had been obtained. The flight was so accurate that the difference between the actual and predicted distance to the planet was only 600 km, roughly the distance

between London and Edinburgh, an error of 0·00005 per cent!

After a successful passage through the asteroid belt, during which time very useful information was sent back to Earth, the probe made its first contact with Jupiter on 26 November when it crossed the bow shockwave, i.e. the boundary between the planet's magnetosphere and the interplanetary magnetic field. It was then at a distance of 108 Jupiter radii. This rather large distance caused some concern amongst the experimenters because of possible damage to equipment by very high radiation, but as it turned out, the equipment survived. Inside the boundary the probe started sending back information on the planet's outer regions. For example, the solar wind velocity dropped from the interplanetary value of 450 km/sec. to roughly half that value and the plasma temperature rose a hundredfold to one million degrees. On the following day the probe crossed the magnetopause at 96 Jupiter radii. The existence of a strong magnetic field was confirmed and estimates were made that if the field was a typical dipole (similar to that of the Earth) the field strength at the planet's surface would be 20 gauss. But events never turn out exactly as expected, because Jupiter was about to spring a big surprise. A few days after entering the magnetosphere, solar activity was such that it pushed back the magnetosphere and very turbulent magnetic conditions existed until a relatively stable magnetosphere was reached at a distance of 50 Jupiter radii. As the probe penetrated nearer to the planet it soon became obvious that the magnetic field was by no means as simple as first thought. Preliminary data indicated that the field could be considered as consisting of two components, the straightforward dipole about eight times stronger than that of the Earth and superimposed on this was a non-dipole field lying along the magnetic equator. The magnetic axis has been found to be tilted at an angle of 15° to the spin axis and the centre of the magnetic field appears to be offset from the centre of the planet by about 18,000 km and positioned at a latitude of 10°S. The polarity of the magnetic field is opposite to that of the Earth and subsequent information has showed that the field strength at the surface is more likely to be in the region of 4 gauss.

The existence of radiation belts around the planet have been known for some time, but one of the main purposes of the flyby was to gain some information on the strength of these belts. Once again Jupiter sprung a surprise. It appears that there is a very high concentration of trapped radiation in the plane of the magnetic equator extending out 15 Jupiter radii and a lesser region out to 35 radii. It is suspected that Jupiter's magnetosphere is governed by electrodynamical processes which are not apparent in the Earth's magnetosphere. As luck would have it, the trajectory of *Pioneer 10* was such that the instruments were about 95 per cent saturated. If the probe had passed 36,000 km nearer to the planet, radiation damage to some of the instruments would have caused a complete breakdown. Even at the actual flyby distance, some equipment such as meteoroid detectors were severely damaged.

The experiments on board the spacecraft were described in detail in last year's *Yearbook* (1974). Normal photography, as used on the Mariner spacecraft was not being attempted because of the huge technological problem of sending the TV signals over such large distances. The spacecraft was spun at a rate of 4·9 rev./min. allowing the telescope to scan Jupiter in strips 0°·03 wide. The light from the planet was first split into two components depending on polarization levels and each of these split again into two parts, these passing through either a blue or a red filter. The signal strength was then recorded and transmitted back to Earth. Each picture took between 25 and 50 minutes to send back. This crude information was then fed into a computer, corrections made for the spinning effect of the spacecraft, the motion of the probe and the rotation of Jupiter during the scanning of the planet. At the time of writing only a few photographs have been released and they show considerable detail in the belts. Of interest are the regions near the terminator, areas which cannot be seen from Earth-based observatories. From the Earth the phase angle can never be greater than just over 10° and so for the first time we have seen Jupiter in a strongly gibbous phase.

The preliminary pictures have shown that at the time of the

flyby, the predominant colouring was brown and grey, although the Great Red Spot was recorded with a strong red coloration. Details within belt systems could easily be identified and it is hoped that when the computer-enhanced versions of the high resolution pictures taken at near encounter become available, details as small as 300 km will be visible, this resolution being about five times better than the best that can be obtained from Earth.

The infra-red radiometer recorded temperatures on both the sunlit and dark sides, the latter not being seen before, and it was found that there was little difference. This is not surprising when one considers the high rotational speed of the planet and it having a relatively stable atmosphere. The radiometer recorded a temperature of about 145°K thus confirming that the planet emits more energy than it receives from the Sun, in fact 2½ times more. Jupiter is therefore not like any of the other planets whose atmospheres are controlled by the amount of energy received from the Sun.

It was also found that the dark belts were 15° cooler than the bright zones. It has also been suggested that the top of the zones consist of ammonia cirrus clouds, these clouds marking the upper limit of rising gases, whilst the cooler descending material is obscured by haze, thus producing the dark appearance. This is readily seen in photographs of regions near the terminator.

The ultra-violet experiments provided very useful information on the composition of the atmosphere. The day-glow observations showed the existence of helium in the atmosphere. Although thought highly likely to be the case, such a result could not be obtained from Earth-based observations. The Jovian atmosphere is now known to consist mainly of hydrogen and helium but in addition contains considerable quantities of ammonia and methane. The actual percentage of helium present has not yet been released, nor has the value of the ratio of hydrogen to helium, a figure of great importance when one starts to consider the origin of Jupiter. The important question to be asked is whether the hydrogen/helium ratio is the same as that found in

the Sun. If it turns out to be so, then with the additional evidence that the hydrogen/carbon and the hydrogen/nitrogen ratios are in fact similar to those existing on the Sun, it can be suggested that the planet has a composition similar to the gas cloud from which the planets condensed, an idea that could help in the solving of the problems associated with the formation of the solar system.

The radio occultation experiment, designed to provide information on an atmosphere by comparing the character of the signal received back on Earth with that transmitted by the probe as it passes behind the planet, showed that the planet had a layered ionosphere. An ionosphere was also detected surrounding the innermost of the four major satellites, Io, and calculations show that the satellite has a very tenuous atmosphere in the region of 10^{-6} millibars.

From the very accurate tracking techniques it has been possible to obtain very accurate values for the masses of the planet and satellites. Preliminary results suggest that the mass of Jupiter is slightly greater than the previously accepted figure. The new figure for the ratio of the mass of Sun to that of Jupiter is 1047·341, compared with previous value of 1047·36. The figure for the oblateness has been found to be 0·065 compared with the 0·060 obtained from optical Earth-based measurements.

It must, however, be emphasized that all the figures given in this article are preliminary figures. After the data have been analysed fully, no doubt revised and more accurate values will be given. Even these revised figures will no doubt be modified if *Pioneer 11* successfully flies past the planet in December 1974. Plans are being made to alter the trajectory so that nearest approach will occur at a fairly high latitude. By doing this, it may be possible to overcome the danger of the equipment being damaged by the intense radiation. Obviously these two probes will not answer anywhere near all the questions being asked at the present time and so our next flood of information will come at the end of this decade when the Mariner Jupiter– Saturn probe, it is hoped, makes a successful flyby.

Decametre-Wave Radio Astronomy of Jupiter

C. H. BARROW

The first successful radio astronomy observations were made in 1932 by Karl Jansky at the Bell Telephone Laboratories in the United States. Jansky recorded radio noise from our galaxy at a wavelength of 15 m and found that the received signal increased when his antenna was directed towards the centre of the galaxy. These important observations received remarkably little notice at the time, however, and it was not until the Second World War that further attention was given to radio astronomy, to some extent as a side effect in radar systems. After the war radio astronomy developed rapidly. First investigations were mainly concerned with the Sun and the Galaxy.

In simple terms, the work of the radio and the optical astronomer may be compared as studies of the two different parts of the electromagnetic spectrum to which the Earth's atmosphere is transparent. The optical astronomer studies the region having wavelengths of the order of 5×10^{-1} cm using a telescope and recording his observations photographically. The radio astronomer studies wavelengths of a few millimetres up to some 30 m using a directive antenna and a pen-recorder to trace the output from a sensitive radio receiver. While the basic operations are similar in principle the practical techniques employed are very different because of the different wavelengths involved. For example, the resolution of an optical telescope (that is the ability to produce separate images of two very close objects) is given by $\theta \propto \lambda/d$ where λ is the wavelength and d is the diameter of the optical system. For good resolution θ must be small. This is obviously far more difficult to achieve in radio astronomy, where typical wave-

lengths are several orders of magnitude greater than the corresponding optical wavelengths. For a radio telescope operating at a wavelength of 3 m to achieve resolution equivalent to the 40-inch Yerkes Observatory refractor would require an antenna of length roughly equal to the radius of the Earth. This is obviously not feasible and elegant techniques, including the use of radio interferometers, have been developed to overcome this problem.

Radio-frequency radiation, originating from Jupiter, was discovered accidentally by Burke and Franklin in April, 1955, at the Carnegie Institution in Washington, during the course of a series of observations of the Crab Nebula at 22·2 MHz, a relatively low-frequency by radio astronomy standards. Powerful outbursts of sporadic noise, which were at first thought to be some type of interference, were found to correlate with the times during which Jupiter was passing through the reception beam of the antenna. Out of a total of thirty-one records, taken when Jupiter was in the antenna beam, nine showed bursts of radio noise.

Decametre-wave radiation from Jupiter has since been studied mostly between about 16 and 26 MHz. At these frequencies the antennas used are very simple in principle, but physically rather large and clumsy, in some cases like large-scale television antennas. Ordinary short-wave communications receivers can be used with little or no modification. Some typical antennas and receiving equipment are shown in Figures 3, 4, and 5. A typical record is shown in Figure 6. (See plates section, pp 181 to 188.)

Following the discovery of Burke and Franklin, Shain, in Australia, reviewed some old records of galactic noise taken during 1950–51 at 18·3 MHz. He found that a number of strong radio disturbances, which had originally been regarded as interference of terrestrial origin, corresponded with times when Jupiter was in the reception beam of the antenna. Direction finding was possible from some of the records and these showed that the source of the noise was within $\pm 1°$ of the position of Jupiter.

Shain introduced a form of analysis, which has since been followed by a number of other workers, in which the times of

the noise outbursts were expressed in terms of central meridian longitude* of Jupiter on a chart covering the entire period of the observations. This is shown in Figure 7(a). Charts for both System I and System II longitudes were prepared and it was found that in the System II chart the noise outbursts were concentrated in a fixed band of longitude while in the System I chart the periods of noise showed a steady drift in longitude throughout the entire period of observations. Shain took this as indicating that the radio emission was concentrated in a localized source which had a rotation period very close to that of the System II central meridian.

Shain also prepared a histogram, Figure 7(b), of the 'number of occurrences' of the noise set against System II longitude. This showed the localization of the source of the noise very clearly, the main peak of the histogram being some 130° wide. A further interesting possibility was also considered briefly by Shain. The main histogram peak might be expected to be 180° wide unless some other effect was present to restrict the emission of the radiation. Shain suggested that an ionosphere on Jupiter might be the cause of such a restriction.

Soon after the publication of the work of Burke and Franklin and of Shain, F. G. Smith reported an unsuccessful attempt to detect Jupiter radiation at rather higher frequencies from old records taken with the Cambridge University 38 and 81 MHz interferometers. Suitable records were available for 16 days in 1952 and 1953 at 38 MHz and for 10 days in 1955 at 81 MHz. The sensitivities of these two systems were considerably better than those employed either by Burke and Franklin or by Shain. In spite of this, however, no Jupiter radiation could be detected and

*The equatorial region of Jupiter appears to rotate slightly faster than does the rest of the planet. Visually observed features are normally recorded in terms of two different systems of central meridian longitude based upon the mean rotation periods of these regions of the planet. System I corresponds to a rotation period of $9^h\ 50^m\ 30^s{\cdot}003$ and refers to the equatorial region. System II corresponds to a rotation period of $9^h\ 55^m\ 40^s{\cdot}632$ and refers to the rest of the planet. System III, introduced later for radio observations of Jupiter, corresponds to a rotation period of $9^h\ 55^m\ 29^s{\cdot}37$.

Smith concluded that the intensity of the radiation must decrease rapidly as the frequency increased.

In the years following the discovery of Jupiter as a radio source, several fundamental investigations in the United States and in Australia began to give a good picture of the general characteristics of the radio emission. The radiation was found to be highly sporadic and confined to a frequency range of about 40 MHz down to less than 5 MHz, the lower limit probably being set by the transparency of the Earth's ionosphere. The emission did not occur all or even most of the time; events at the higher frequencies were rather unusual. Observations at the lower frequencies were difficult because of radio interference and the majority of studies were, therefore, conducted at frequencies close to 20 MHz.

The radiation usually occurs in bursts having durations varying, typically, from about 0·2 to 2·0 seconds as shown in Figure 6. Many of the burst intensities are high and are exceeded only by strong solar bursts. The terms 'event' and 'burst' were introduced to signify, respectively, a period of Jovian radioactivity (or Jovian noise storm) and an individual intensity surge within a period of activity. Events may occur simultaneously over the entire frequency range, although they are most often confined to the lower frequencies, while a burst may have a bandwidth of only one or two MHz or less.

Shain's basic histogram analysis was refined by the use of computers with observational data extending over several years. A rotation period of $9^h\ 55^m\ 29^s{\cdot}37$, was found to fit the radio observations better than either the System I or System II periods and histograms of the observations came to be presented based upon this 'radio rotation period' or 'System III' period. A typical example is shown in Figure 8, where the presentation is further refined by statistical smoothing of the data and by introducing the term 'occurrence probability' rather than 'number of occurrences'. Use of the quantity occurrence probability eliminates from the analysis periods when Jupiter might have been in the reception beam of the antenna but for some reason (perhaps poor

receiving conditions due to interference) could not be observed or identified with any certainty. It can be seen from Figure 8 that the probability of occurrence of an event varies as Jupiter rotates. Between about 15 and 30 MHz there is one well-defined maximum (A) and one well-defined null (D) with two smaller peaks B and C. Below 10 MHz two maxima, about 180° apart are observed. The curve shown in Figure 8 represents a longitude profile of the occurrence probability but it does not tell us anything about the latitude profile of the emission. The peaks A, B, and C have come to be known as 'sources', however, with the implication of a small localized emitting region corresponding to each. There is no apparent relation between any of these so-called sources and any of the well-known optical features on the planet.

It had been suggested by Gallet that the polarization of the radiation should be studied, as this might provide a means of investigating the possible existence of a magnetic field and an ionosphere on Jupiter. Subsequent investigations by various workers indicated that most of the radiation is polarized in the right-handed sense (see Figure 6) although left-handed polarization sometimes occurred. The proportion of left-handed polarized events increases at lower frequencies (below 18 MHz) and appears to be related to the B and C sources. The degree of polarization is generally rather high.

So far we have only considered the results of observations made at fixed frequencies. Swept-frequency, or radio spectrograph, observations have also been used to study Jupiter, notably by Warwick using the solar spectrograph at the High Altitude Observatory in Colorado. In this technique the signals are received from a broad frequency-band antenna and the radio receiver tuning is swept electronically through a given range. The sweep of an oscilloscope beam is driven synchronously with this and the receiver output is made to modulate the intensity of the spot. Each cycle thus produces a line of varying intensity across the oscilloscope corresponding to tuning through the given frequency range. This is photographed by a slowly moving strip of film, so that the resulting display is a presentation of intensity

variation of the film against time (the length of the film strip) and frequency (the width of the film strip). A typical example is shown in Figure 9.

Fixed frequency observations are thus rather like cross-sections along the length of the time-frequency plane of the film. They can, therefore, show the detailed time-structure of a period of activity well. They cannot, however, show the variations with frequency which are seen better from swept-frequency records.

Swept-frequency observations demonstrate very effectively the narrow bandwidths of individual bursts and also that the centre frequency of the activity may change with time. The direction of the change appears to be associated with the central meridian longitude of Jupiter, a negative drift (that is from high to low frequency) being predominantly associated with source A and a positive drift predominantly with sources B and C although reversals may sometimes take place.

In 1964 an interesting new development was announced by

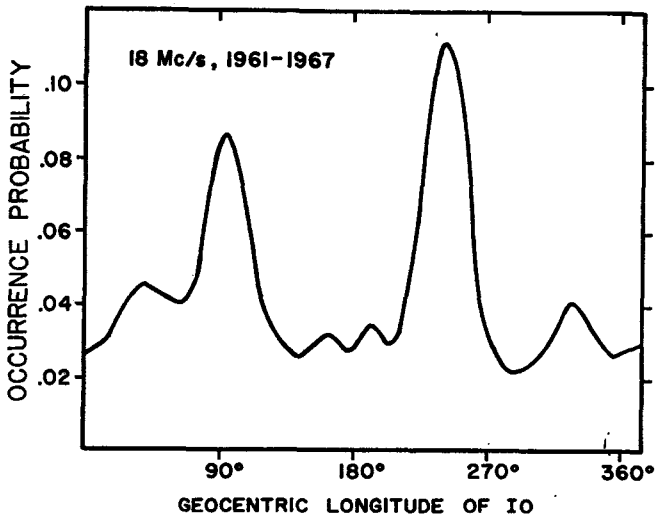


Figure 1. Smoothed histogram showing the Io effect for 1961–1967 at 18 MHz.

Bigg, who discovered that periods of Jupiter activity were closely associated with the position of the Galilean satellite Io relative to the Earth-Jupiter line. This is shown in Figure 1 in which the smoothed occurrence probability is shown as a function of the geocentric longitude of Io. The peak close to 90° geocentric longitude appears to be associated with the Jovian B source, whereas the peak close to 240° geocentric longitude is associated with the A and the C sources. This effect is so pronounced that it has even been used as a means of predicting times when Jupiter may be expected to be active.

Individual bursts may show a large amount of structural detail. Time-structured features having durations of about 0·2 to 2·0 seconds and longer (sometimes called L-bursts*) are generally believed to be superimposed, within the interplanetary medium, after original radiation has left Jupiter. Much shorter duration features (sometimes called S-bursts, millisecond pulses or Is pulses*) ranging from 0·2 sec to as little as 20 μsec are sometime-

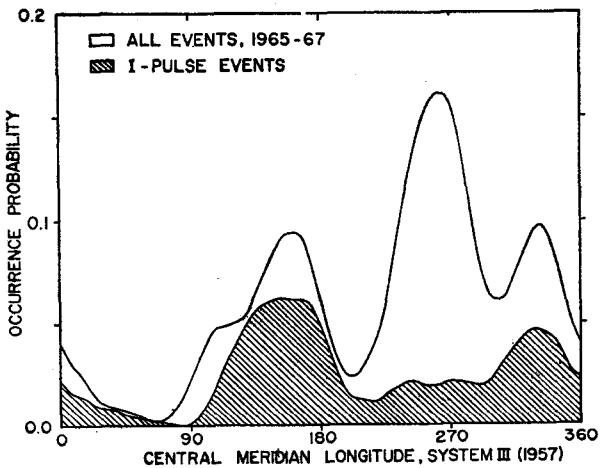


Figure 2. Smoothed histograms comparing Jupiter radiation for 1965–1967 with millisecond pulse emission (I-pulses) for the same period.

*A number of different classification schemes have been used in the literature.

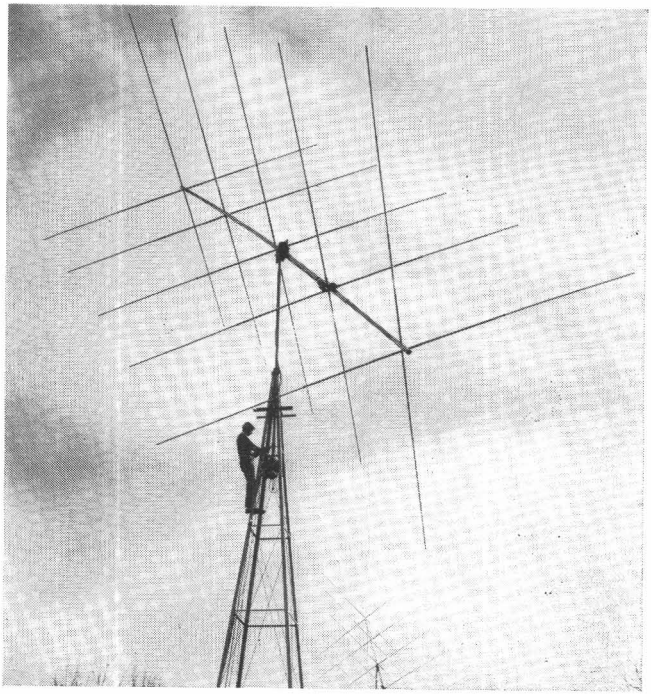
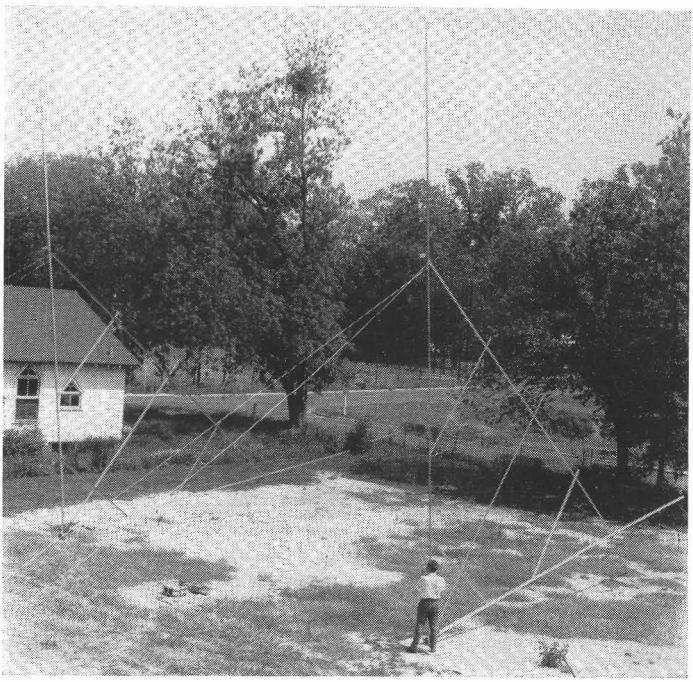


Figure 3. Two 18 MHz Yagi antennas cross-mounted on a single boom for use as a radio polarimeter.

Figure 4. A 22 MHz square corner-reflector antenna.



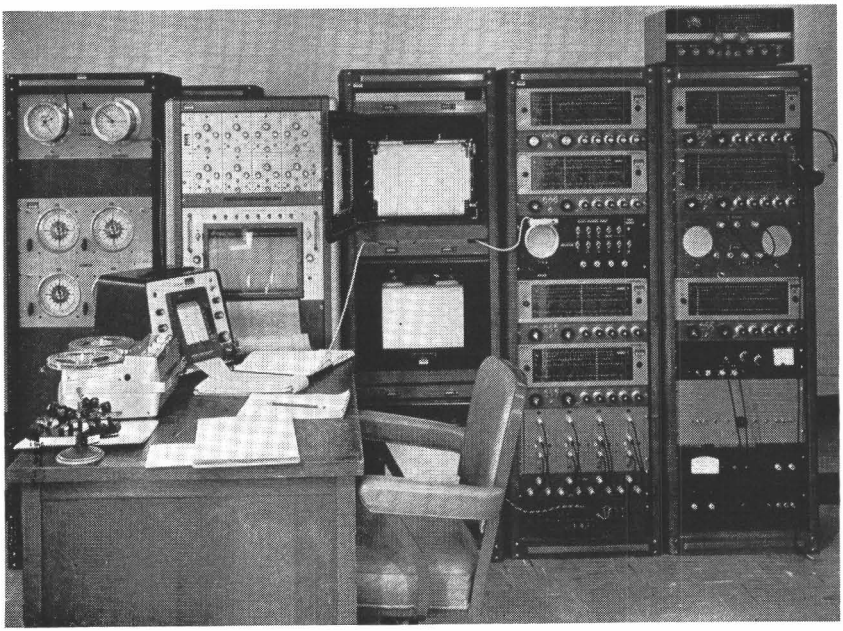


Figure 5. Fixed frequency receiving equipment for the study of Jupiter.

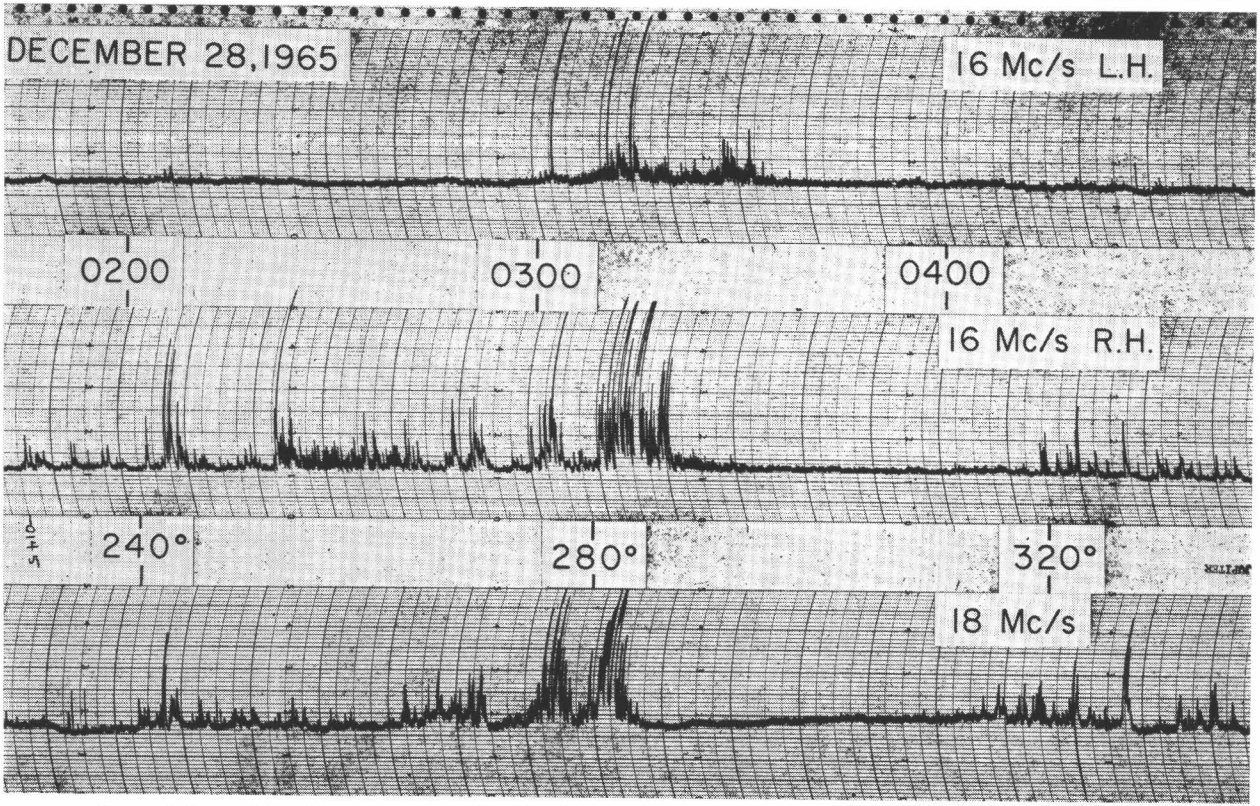
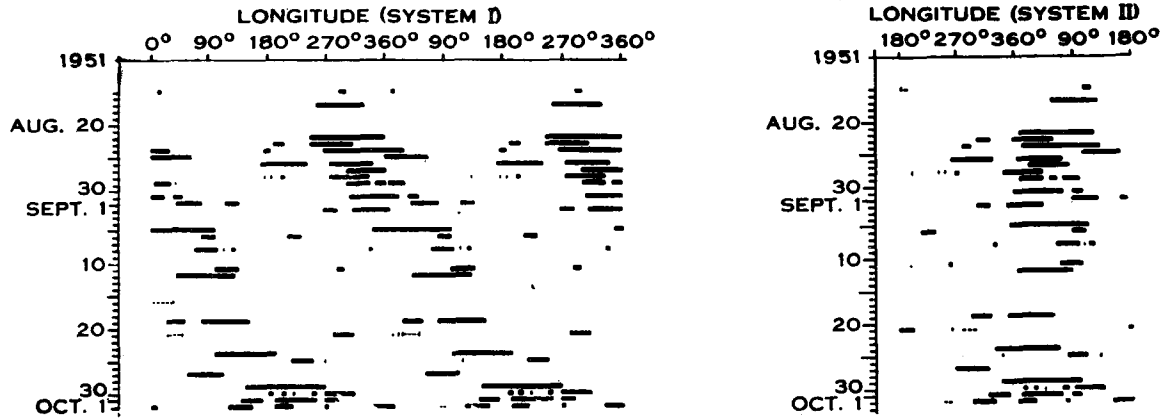


Figure 6. Typical fixed frequency records of Jupiter radiation. Left- and right-hand components of polarization are shown at 16 MHz and total power at 18 MHz.


LONGITUDE (SYSTEM I)
0° 90° 180° 270° 360° 90° 180° 270° 360°
1951
AUG. 20
30
SEPT. 1
10
20
30
OCT. 1
LONGITUDE (SYSTEM II)
180° 270° 360° 90° 180°
1951
AUG. 20
30
SEPT. 1
10
20
30
OCT. 1

Fig, 7a.

Figure 7. The basic histogram analysis introduced by Shain: (*a*) (opposite) Periods of radio emission compared in System I (left-hand section) and in System II (right-hand section). (*b*) (below) Central meridian longitudes; the histogram corresponding to the System II analysis.

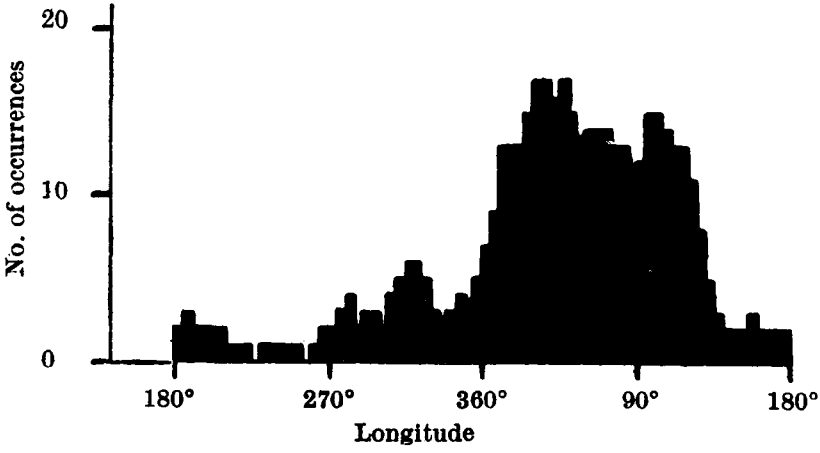


Fig. 7b.

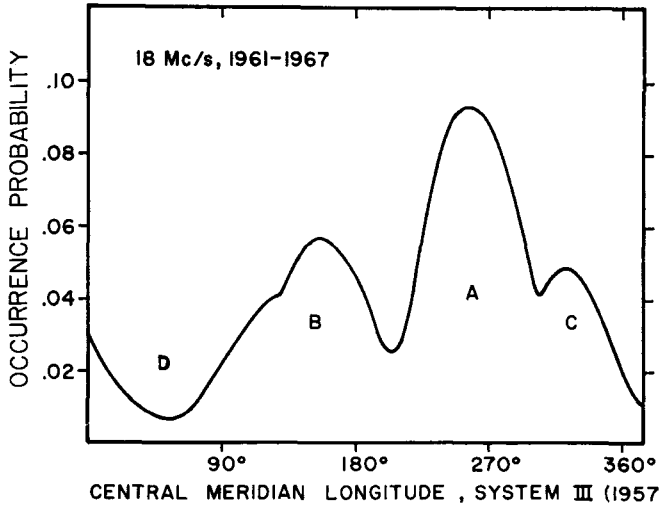


Figure 8. Smoothed histogram of Jupiter's radio emission for 1961–1967 at 18 MHz.

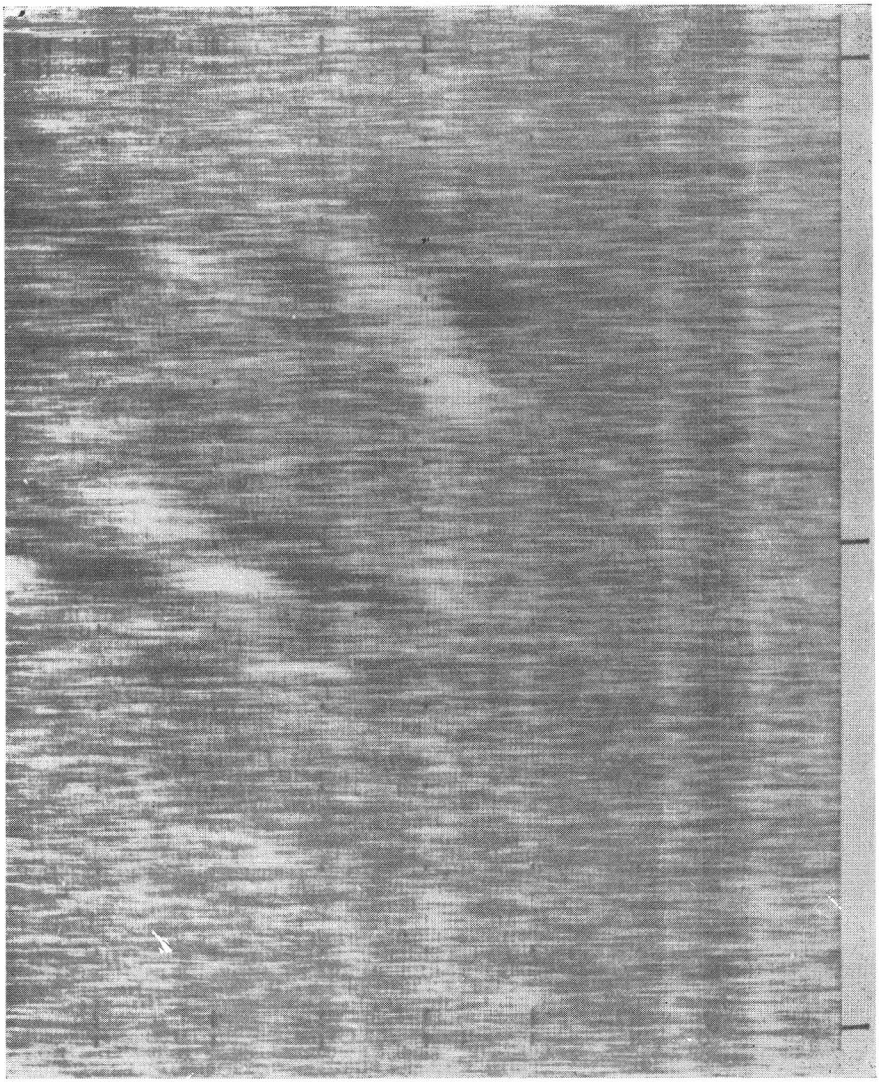


Figure 9. Typical swept-frequency record (after J. W. Warwick).

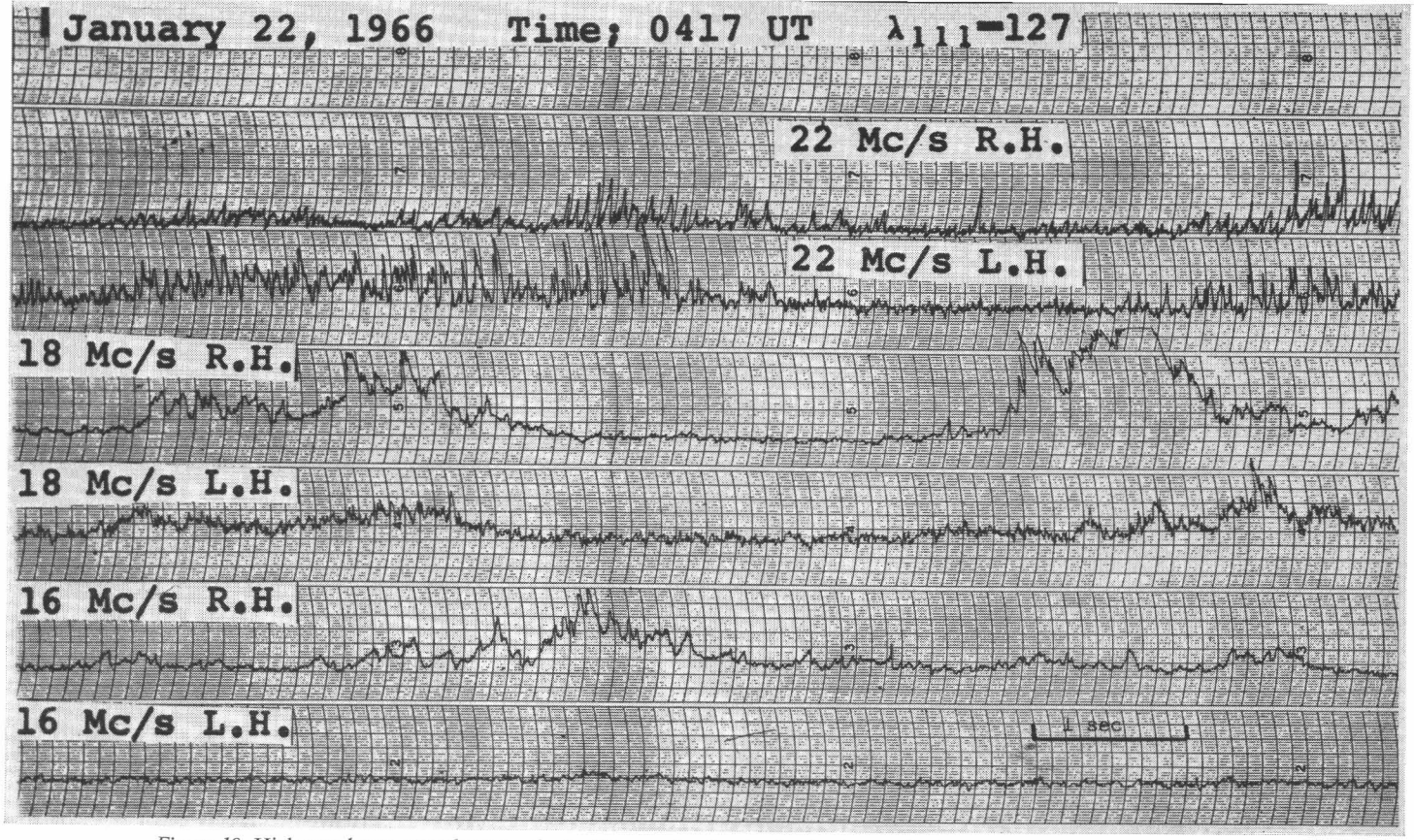


Figure 10. High-speed pen-recorder record of millisecond pulses in the Jupiter radiation at 22 MHz not simultaneously present at 16 and 18 MHz where L-bursts are recorded (after Baart, Barrow, and Lee).

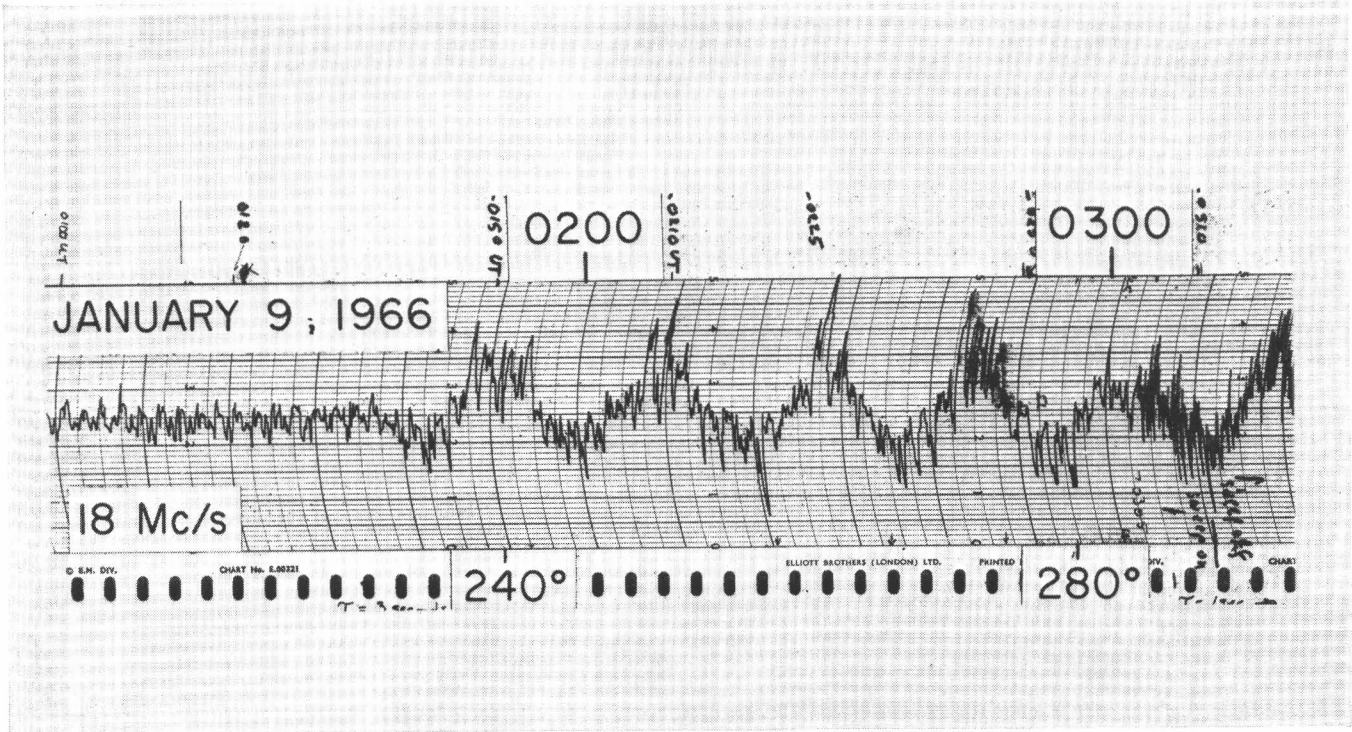


Figure 11. Typical interferometer record of a Jupiter noise storm at 18 MHz.

observed and these are believed to originate at Jupiter. The intensities of these fast pulse-like features may be very high indeed, as shown in Figure 10. They appear to be associated with the B and the C sources. This can be seen in the histograms of Figure 2.

An obvious question that the reader may ask is, 'How can one be certain that the radiation is really from Jupiter in view of the difficulties from stations and terrestrial interference at decametre-wave frequencies?'

Several procedures have been adopted in order to minimize uncertainties. Instrumentally, the interferometer is the most reliable. In this (which is the radio analogue of the Michelson-Morley experiment) two separated antennae, on an east-west baseline a number of wavelengths long, feed a single receiver with equal length transmission lines. Radiation from a source at upper culmination will therefore be received simultaneously by each antenna and delivered in phase to the receiver. If the source is a few degrees away from upper culmination a phase difference will be introduced when the signals are combined at the receiver. Thus, as the Earth rotates, the receiver output will go through a series of maxima and minima (known as 'fringes') as the radio source passes through the reception beam of the antennae. Radiation from the required source will show the fringe system while terrestrial interference will not. An example of an interferometer record of the Jupiter radiation is shown in Figure 11.

A different technique is to use so-called 'aural monitoring' in which an observer, who is present during each observation, makes the identification based upon a number of common-sense criteria. These are as follows:

1. Jupiter must be within the reception beam of the antenna.
2. The pen-recorder must show a deflection clearly visible above the background noise.
3. The signal must have the characteristic sound and time-structured features of the Jupiter radiation.
4. The signal must not tune out over a small frequency band of

about ±0·25 MHz. This distinguishes the radiation from a distant station.

5. The signal must not be identifiable as being of terrestrial origin. Static pulses, car ignition, and power-line radiation are the most common types of interference. All of these cover a very broad frequency band and each has a characteristic sound quite different from Jupiter radiation. While Jupiter bursts cover a sufficient frequency bandwidth to permit the criterion (4) above, they do not normally spread over more than a MHz or so instantaneously.
6. Jupiter radiation shows a characteristic polarization while interference is usually randomly polarized.
7. Over a period of several weeks the Jupiter radiation is correlated with the System III rotation period.

These criteria are most applicable to fixed frequency observations, of course.

Antennae having a null in the direction of Jupiter have been used for comparison with the working antennae. Observing conditions are much improved at night-time and the best time for observation is when Jupiter is close to upper culmination during the early morning hours, from midnight until about 6 a.m., local time.

There are several indications that the Jovian radio emission may be in some manner related to Solar activity. Studies of this problem usually involve the application of statistical methods to search for correlation between the radiation from Jupiter and some indicator of Solar activity, such as sunspot number or the geomagnetic index. As both the Solar and the Jovian data contain periodicities of their own, however (over and above any possible correlation effects), the results of such studies have to be evaluated with caution. Both long- and short-term effects may be present.

The long-term inverse sunspot effect, perhaps the best established result, is due to A. G. Smith and his colleagues at the University of Florida. Over a period of some sixteen years it appears (as shown in Figure 12) that the radio emission from

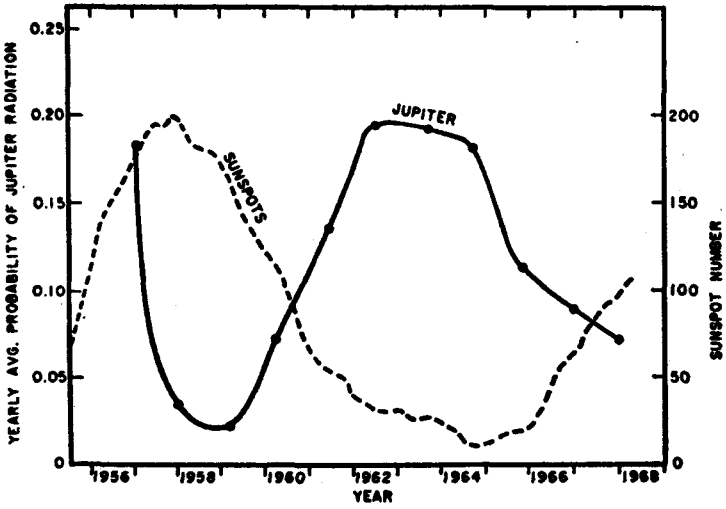


Figure 12. The inverse sunspot effect from 1957–1968 (after A. G. Smith).

Jupiter increases at sunspot minimum and vice-versa. The evidence in support of this looks very convincing and the effect is probably real but it must still be remembered that the duration of the analysis is, so far, only about 1·5 sunspot cycles. Also, the period of the sunspot cycle is itself almost equal to the 11·9 year revolution period of Jupiter.

Short-term correlation effects are more uncertain than the inverse sunspot effect and some workers believe that one cannot establish any conclusive results because of periodicities (for example, the rotation period of the Sun, the rotation period of Jupiter, the revolution period of Io) concealed in the data. While there have been good indications recently of short term correlation effects linking the Jovian radio emission with the solar wind the problem of concealed periodicities cannot be completely eliminated. It may be many years before sufficient data is available to establish a really conclusive result.

Some twenty theories of the radio emission have been proposed covering ideas ranging from Jovian thunderstorms to focusing

by Jupiter's ionosphere of radio emission from a distant star, plasma oscillations, and dynamo effects simulated by the motion of Io through a Jovian magnetosphere. In fairness it must be stated that the problem is difficult and it is not helped by the lack of actual measured values of quantities which might affect the radiation. Unfortunately, by the very nature of the observations, some of the results tend to be qualitative rather than quantitative. Estimates, even of such basic parameters as the magnetic field and the electron density in Jupiter's upper atmosphere vary by orders of magnitude in the theoretical literature.

Ellis and McCulloch, basing their ideas upon conditions at the Earth giving rise to VLF emission, suggested that the Jupiter radiation might be due to cyclotron radiation emitted by bunches of electrons spiralling down high-latitude magnetic field lines in a Jovian magnetosphere. Radiation emitted by the moving electrons could only escape if the electrons were accelerated sufficiently for the emitted frequencies to be Doppler-shifted above the critical frequency of the Jovian magnetosphere.

Warwick suggested that the radiation took place at frequencies close to the gyrofrequency and was due to electrons moving down the magnetic field lines and generating Čerenkov radiation which escaped after reflection at some lower and denser layer in the planet's ionosphere. The theory required an asymmetric magnetic field at Jupiter in order to explain the characteristic longitude profile of the emission shown in Figure 8.

Both of these theories were originally proposed before the discovery of the Io effect and both have since been modified to make allowance for the effect.

In a more recent theory due to Goldreich and Lynden-Bell, Io is required to be weakly electrically conducting and moving through a low-density magnetosphere surrounding an ionosphere which co-rotates with Jupiter. A voltage is induced at Io and a current flows from the satellite through the ionosphere. Cyclotron radiation is produced by the moving electrons which constitute the current flow.

This article is mainly concerned with the low-frequency or

decametre-wave radiation from Jupiter. Remarkable results have also appeared from much higher frequency, or decimetre-wave, observations, however.

Prior to 1958, it was generally agreed that microwave radiation gave an indication of the brightness temperature of a planet and first observations by Mayer, McCulloch and Sloanaker, at a wavelength of 3·15 cm appeared to be consistent with this, indicating a value of 145 $\pm$ 26°K in reasonable agreement with infra-red temperature measurements of about 130°K. Other workers confirmed this result at nearby wavelengths. In 1958, however, McClain and Sloanaker found a temperature of 600°K at a wavelength of 10 cm. Subsequent investigations at 21, 31, and 68 cm wavelengths showed that the radio brightness temperature increased with wavelength to about 5×10^4°K at 70 cm. Clearly, some non-thermal process was also present in addition to the thermal radiation. Using the twin 90-ft dishes as an interferometer, at the Owens Valley Radio Observatory in California, it was found that the equatorial diameter of the radio source was some three times larger than the optical diameter of the planet. This was interpreted as indicating the presence of a Van Allen type radiation belt at Jupiter, similar to that which surrounds the Earth. It was also shown, using the same instrument that the magnetic axis of Jupiter is inclined at 9° to the rotation axis. The magnetic poles were found to be at System III longitudes of 200° and 20°, the former roughly coincident with the main decametre-wave A source.

It is generally agreed that the decametre-wave radiation is due to synchrotron radiation by high energy electrons trapped in the Jovian magnetic field.

Recent Advances in Astronomy

PATRICK MOORE

It is seldom that a month now passes without some worthwhile new development in astronomy—or in space-research, which can no longer be separated from what we may call 'classical astronomy'. Rapid progress is being made both with respect to our immediate part of the universe, the Solar System, and to stellar and galactic research. Professional astronomers naturally concentrate mainly upon the latter, but the latest developments have been largely covered elsewhere in this *Yearbook*, and so it may be best here to deal with what has been happening in our immediate neighbourhood.

No more manned probes have been sent to the Moon, and none has been announced for the near future. The main emphasis is upon the space-shuttle, and upon the Russo-American link-up in orbit; the two commanders are Alexei Leonov for the U.S.S.R. and General Tom Stafford for the U.S.A. Both are space veterans; Leonov made the pioneer 'space-walk', and Stafford was commander of Apollo 10. All the plans seem to be going well, both from the technical and the personal point of view (it is interesting, for instance, to note that the Russians have been busily learning English, while the American astronauts are now fluent in Russian!). On 3 July the Russians sent up Soyuz 14, their first manned research station for some time, which carried Cosmonauts Popovich and Artyukhin, and which came down safely on 19 July. Soyuz docked with the orbiting station Salyut-3, and was no doubt part of the rehearsal procedure for the link-up with the Americans which is now becoming imminent.

Of the unmanned vehicles, special note must be made of Mariner 10, which by-passed first Venus and then Mercury. The photographs of Venus from close range are immensely informative; for the first time the cloud structure has been revealed—and Venus proves to be an even stranger world than had been thought. The four-day rotation period of the upper layer is now quite definite, though it is generally believed that the planet itself has a retrograde rotation in a period of 243 days—longer than Venus's 'year'. Mercury, as had been generally expected, proved to be cratered, and pictures of it are strikingly similar to those of lunar scenery. Less generally expected was the presence of a magnetic field, which is admittedly weak but it is still measurable. The planet is also very dense; it has a specific gravity of 5.44, and this may indicate a large iron core extending out for around 70 per cent of the radius. The Mercurian atmosphere, detected by the ultraviolet experiment on Mariner 10, has a ground pressure of 2×10^{-9} millibars, and is made up chiefly of helium, neon, argon, and xenon, all of which are inert gases. The helium and neon may be captured from the solar wind, but it is also possible that radioactive minerals in the crustal rocks release a certain amount of helium and argon. Of course, the 'atmosphere' of Mercury is so tenuous that for all practical purposes it may be classed as a vacuum.

It is interesting to compare these results with the views expressed by E. M. Antoniadi, the great planetary astronomer whose monograph published originally in 1934 was, until the spring of 1974, accepted as the main source of information about Mercury.* Antoniadi believed that the atmosphere must be dense enough to support 'clouds', which he regarded as commoner than those on Mars. This is now known to be impossible; but it is strange that so experienced an observer, using very powerful equipment, could have been so badly in error. Despite Mariner 10, we do not yet know nearly as much about the innermost planet as we would like to do.

*Published in 1974 in English translation. See 'Some Recent Books' at the end of this *Yearbook*.

Pioneer 10, having by-passed Jupiter in December 1973, is now on its way out of the Solar System, carrying the celebrated plaque which might give a clue as to its origin in the admittedly unlikely event of its being located by an alien civilization far across the Galaxy. Pioneer 11, due to encounter Jupiter in late 1974, has been given a course adjustment which will swing it towards Saturn, and by-pass the Ringed Planet in 1979. This is beyond the official operative life-time of its equipment; but deep-space probes often work for longer than scheduled, and we can only hope that Pioneer 11 will still be in touch when it nears Saturn.

Natural satellites have also been in the news. In Jupiter's system, Io is now known to have an excessively tenuous atmosphere, while Callisto, according to Russian results, may be ice-covered. Titan, the senior attendant of Saturn, is causing great interest among theorists, because it now seems to have an atmosphere with a ground pressure ten times as great as that on Mars; there may well be clouds there. The atmosphere is thought to be 'cyclic', but at all events Titan is assuming great importance, and there is even talk of sending a probe with Titan, rather than Saturn itself, as the main target.

As we all know, Kohoutek's Comet, expected to be spectacular at the end of 1973 and the start of 1974, signally failed to come up to expectations, but it was well studied by the astronauts on the Skylab space-station, and was scientifically important. Since then we have had Bradfield's Comet, which was by no means brilliant, but did become bright enough to be visible with the naked eye; and among the periodical comets, the familiar Encke has been back once more. Unfortunately we cannot be sure of seeing any bright comet before Halley's returns to perihelion in 1986.

Since I wrote the corresponding article in the 1974 *Yearbook*, there have inevitably been sad losses to astronomy. Dr Gerard P. Kuiper, one of the greatest of planetary researchers, died in late 1973; his work was of fundamental importance, and it is surely fitting that the first named crater on Mercury should be called 'Kuiper'. Dr E. M. Lindsay, Director of the Armagh

Observatory, died in July 1974; as well as being an eminent astrophysicist he was a great 'popularizer' and organizer. He raised Armagh from the status of a minor to a major establishment, and he was responsible for the setting up of the Armagh Planetarium. (He has, of course, contributed to past *Yearbooks*.) Amateur astronomy, too, has had its losses; it seems right to mention here Phil Ringsdore, for many years Secretary of the British Astronomical Association's Lunar Section, whose organizational work and personal qualities were so greatly appreciated by both amateurs and professionals. He was one of the 'great amateurs', his death, in the spring of 1974, is deeply regretted. And just as this article was in press I heard, to my deep sorrow, of the passing of another great amateur, David P. Barcroft of California; a man not to be forgotten—and who is sadly missed.

I am only too painfully aware that this survey of recent events is very sketchy and incomplete, and that much has been omitted; no doubt, too, much more will have happened before this *Yearbook* is actually published. Astronomy is no longer the more or less static science that it used to be not so very long ago.

PART THREE

For Stellar Observers

Hunting the Messier Objects

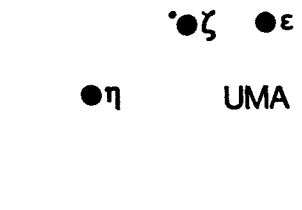
PATRICK MOORE

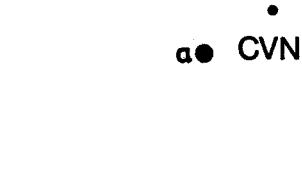
Every astronomer, amateur or professional, knows the Messier catalogue of star-clusters and nebulæ. Messier was essentially a comet-hunter; he compiled his catalogue, in the latter part of the eighteenth century, because he found himself wasting time upon objects in which he was not interested – and, ironically, he is now remembered for his catalogue rather than the thirteen comets that he discovered between 1760 and 1798! The M numbers are still used, though professionals prefer to refer to the NGC or *New General Catalogue* numbers.

There are just over a hundred Messier objects, some of which are remarkably prominent while others are decidedly dim. The following notes are not intended to be complete; all I have set out to do is to list some of the Messier clusters and nebulæ which are likely to be of interest to the owner of a small telescope. Anything beyond the range of a 3-inch refractor has been unceremoniously excluded. This is a pity, since it means leaving out what is perhaps the most fascinating object of all: M.1, the Crab Nebula near Zeta Tauri, which we know to be the remnant of the 1054 supernova, and which contains a pulsar. I have seen it with a 3-inch, but it looks like nothing more than an excessively faint blur, and photographs taken with powerful equipment are needed to bring out the remarkably involved structure. So let us look toward some rather brighter entries in the list.

M.3 (NGC 5272) *Canum Venaticorum.* RA $13^h\,40^m$, decl. $+28°38'$. *Figure A.*

A bright globular cluster, 48,000 light-years away; integrated magnitude, $6\frac{1}{2}$. Messier himself discovered it in 1764. Binoculars





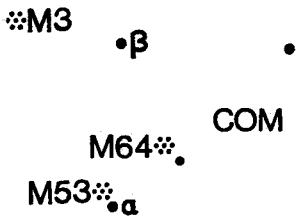


Figure A.

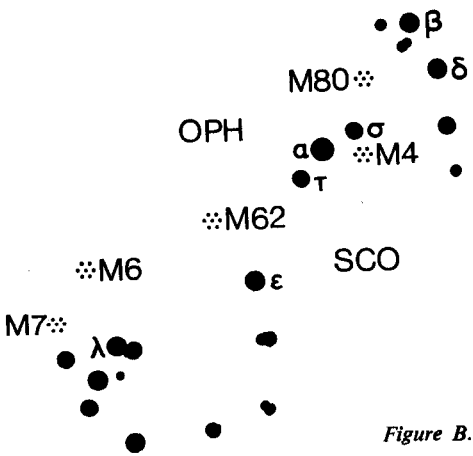


Figure B.

will show it, and with a small telescope the outer parts are resolvable. The nearest guide-star is Beta Comæ.

M.4 (NGC 6121) *Scorpii.* RA $16^h\ 21^m$, decl. $-26°24'$.
Figure B.

Another bright globular, but at a mere 7,500 light-years it is one of the nearest members of its class. Integrated magnitude, $6\frac{1}{2}$; it is easy to find, as it lies only $1\frac{1}{2}°$ west of Antares.

M.5 (NGC 5904) *Serpentis.* RA $15^h\ 16^m$, decl. $+2°16'$.
Figure C.

Yet another bright globular; magnitude $6\frac{1}{2}$, in the same low-power field as Fl.6 Serpentis. Its distance is 27,000 light-years, but it is easily resolved.

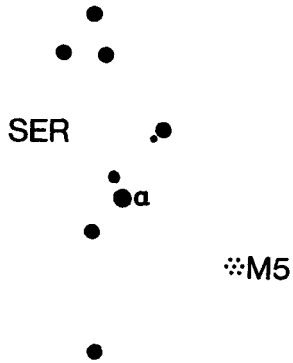


Figure C.

M.6 (NGC 6405) *Scorpii.* RA $17^h\ 37^m$, decl. $-32°11'$.
M.7 (NGC 6475) *Scorpii.* RA $17^h\ 51^m$, decl. $-34°48'$.
Figure B.

Two magnificent open clusters near the Scorpion's sting; both are naked-eye objects (magnitudes $5\frac{1}{4}$ and 4 respectively) though unfortunately very low from Britain. Both are brilliant and rich; very low powers are needed to bring out their full beauty.

M.8 (NGC 6530) *Sagittarii.* RA $18^h\ 00^m$, decl. $-24°23'$.
Figure D.

The Lagoon Nebula; not far from Lambda Sagittarii. It is a gaseous nebula of the emission type. The integrated magnitude is 6, and so it is not hard to locate even though a small telescope is unable to show the beauty of the bright and dark material.

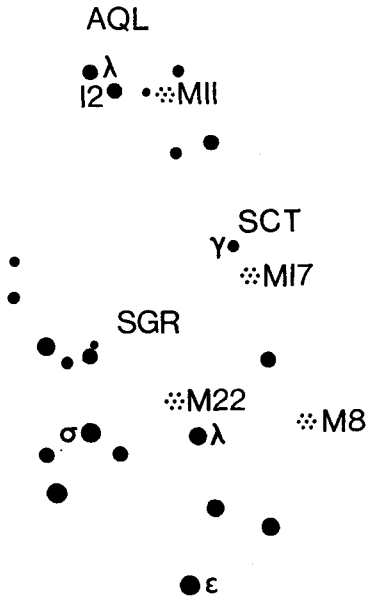


Figure D.

M.11 (NGC 6705) *Scuti.* RA $18^h\ 48^m$, decl. $-6°20'$.
Figure D.

The 'Wild Duck'; a galactic cluster at 5,500 light-years from us. It is easily found, since its magnitude is only just below 6; it lies near Lambda and 12 Aquilæ. The shape is rather like that of a fan. This is certainly one of the loveliest of all open clusters.

M.13 (NGC 6205) *Herculis.* RA $16^h\ 40^m$, decl. $+36°33'$.
Figure E.

The finest northern globular cluster; just visible with the naked eye, and easy in binoculars. A moderate telescope will resolve it, even though it is 22,500 light-years away. It was discovered by

Halley in 1714, and is a favourite object for amateurs. It lies between Zeta and Eta Herculis, rather closer to Eta.

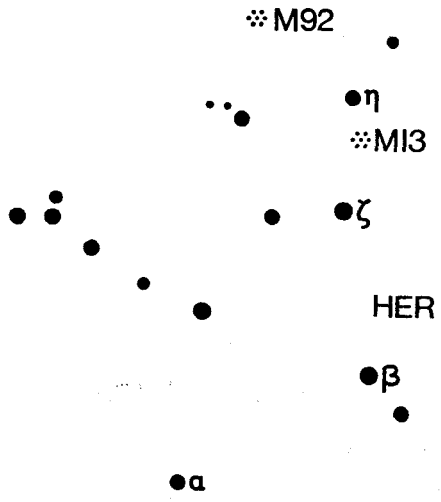


Figure E.

M.17 (NGC 6618) *Sagittarii.* RA $18^h\ 18^m$, decl. $-16°12'$.
Figure D.

The Omega Nebula: a gaseous emission nebula, magnitude 7, distance 5,900 light-years. It is near Gamma Scuti. Only the main portion is visible with a small telescope, but it is worth finding.

M.22 (NGC 6656) *Sagittarii.* RA $18^h\ 33^m$, decl. $-23°58'$.
Figure D.

A fine 6th-magnitude globular, again near Lambda Sagittarii. It is relatively loose, and so is easy to resolve.

M.27 (NGC 6853) *Vulpeculæ.* RA $19^h\ 57^m$, decl. $+22°35'$.
Figure F.

The Dumbbell Nebula; the finest of all the planetaries, with a magnitude of $7\frac{1}{2}$ and a distance of just less than 1,000 light-years. It is only 3° from Gamma Sagittæ, and its form is not hard to

make out, though admittedly a 3-inch refractor will not show it properly. However, it is quite unmistakable.

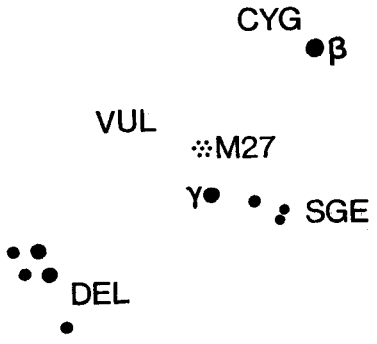


Figure F.

M.31 (NGC 224) ***Andromedæ.*** **RA 00^h 40^m, decl. +41°00′.**
Figure G.

The Great Spiral. Magnitude 5; distance 2,200,000 light-years. This is so well known that it need not be further described here – except to stress that in a small aperture it is disappointing! Its main companion, M.32, is an elliptical galaxy of magnitude 8¾.

M.33 (NGC 598) ***Trianguli.*** **RA 01^h 31^m, decl. +30°24′.**
Figure G.

Though the Triangulum Spiral has an integrated magnitude of above 7, it is not really an easy object; the surface brightness is low, and it is perhaps most easily located with good binoculars, roughly between Alpha Trianguli and Beta Andromedæ.

M.34 (NGC 1039) ***Persei.*** **RA 02^h 39^m, decl. +42°34′.**
Figure G.

Another of Messier's personal discoveries; 1,500 light-years away. An open cluster; its magnitude is 5½, so that it is easy in binoculars, roughly between Algol and Gamma Andromedæ.

(Note that the double cluster in the Sword-Handle of Perseus, H.VI.33-4, is not included in Messier's catalogue – perhaps because it could not possibly be mistaken for a comet!)

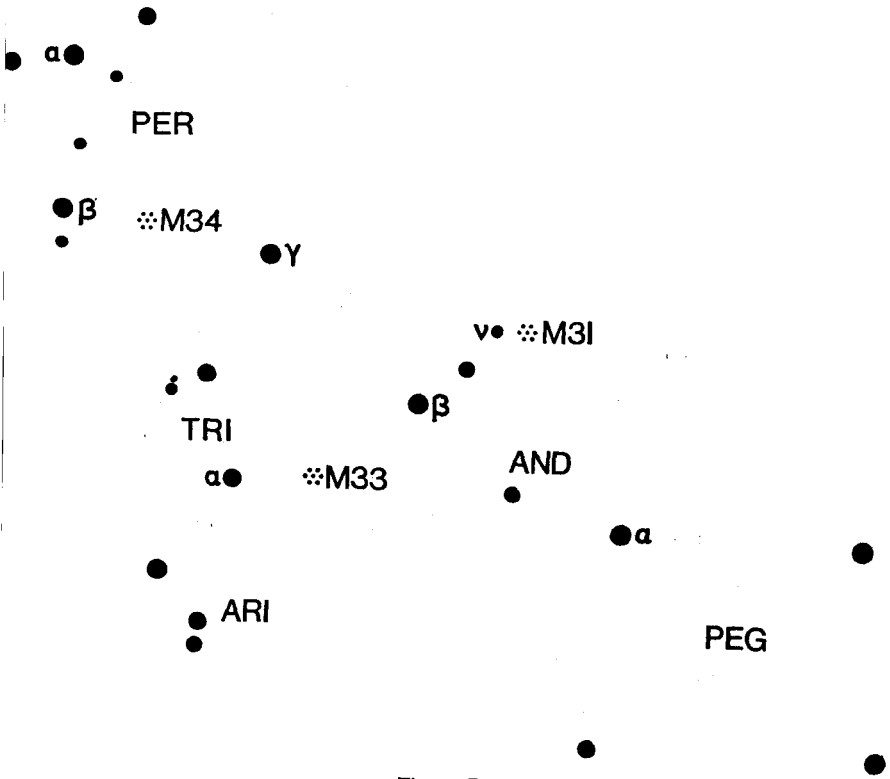


Figure G.

M.35 (NGC 2168) *Geminorum.* RA 06^h 06^m, decl. +24°21′.
Figure H.

One of the finest of all open clusters; magnitude 5½, distance 2,900 light-years. It lies near Mu, Eta and Fl.1 Geminorum, and is magnificent even in small telescopes.

M.41 (NGC 2287) *Canis Majoris.* RA 06^h 45^m, decl. −20°41^h.
Figure H.

A bright open cluster; magnitude 4½, distance 1,600 light-years. It is not far from Sirius, and so remains rather low in Britain, but it is a fine object well worth finding.

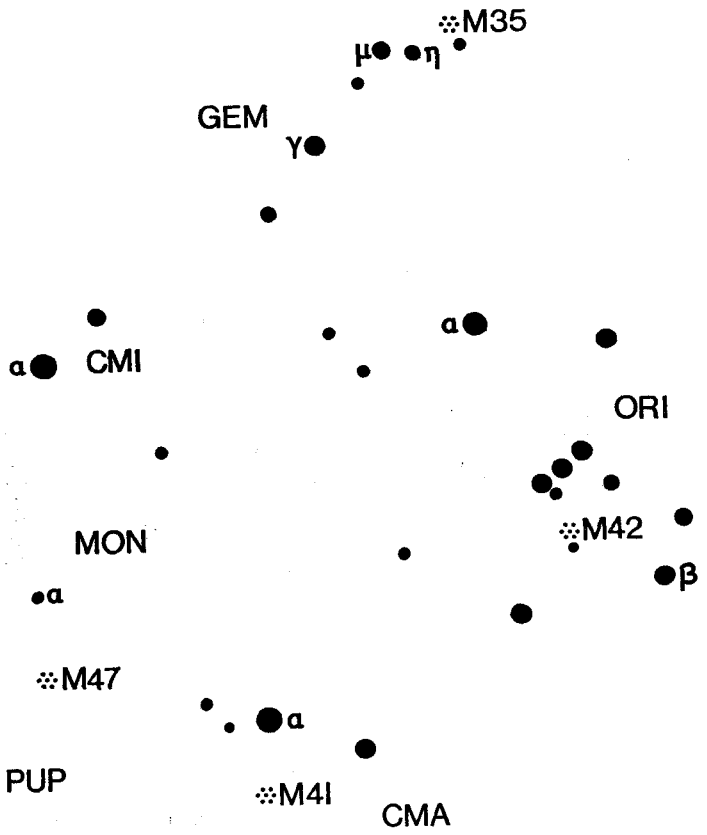


Figure H.

M.42 (NGC 1976) *Orionis.* RA $05^h\ 33^m$, decl. $-05°25'$.
Figure J.

The Great Nebula in Orion's Sword; discovered by Peiresc in 1610. It is strange that it was not described earlier, as it is so easily visible with the naked eye. A 3-inch telescope will show the four main components of the famous multiple star Theta Orionis, the 'Trapezium'.

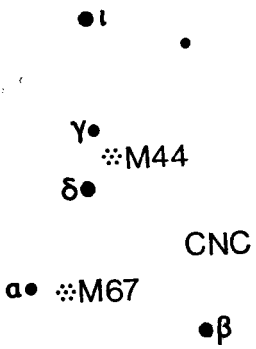


Figure J.

M.44 (NGC 2632) *Cancri.* RA 08^h 37^m, decl. +20°00′.
Figure J.

Præsepe; apart from the Pleiades perhaps the finest of the open clusters. It is easily visible with the naked eye; Delta and Gamma Cancri provide excellent guides to it. It is 525 light-years away. The best views of it are obtained with low powers, since it has a diameter of some 70 minutes of arc and higher magnifications will show only part of it at any one time.

M.45 *Tauri* (not in the NGC). RA 03^h 44^m, decl. +23°58′.

The Pleiades: 410 light-years away. The brightest star is the third-magnitude Alcyone. Binoculars show it superbly; it is, of course, a familiar naked-eye object.

M.47 (NGC 2422) *Puppis.* RA 07^h 34^m, decl. −14°22′.
Figure H.

An open cluster; magnitude 5, distance 1,750 light-years. It is visible with the naked eye not far from Alpha Monocerotis, and contains some fairly bright stars. Near it is the less obvious open cluster M.46.

M.53 (NGC 5024) *Comæ.* RA 13^h 11^m, decl. +18°26′.
Figure A.

A globular cluster, magnitude 7½; distance 69,000 light-years, so that it is one of the more remote members of its class. It is

easy to find, as it lies only one degree from Alpha Comæ. It is relatively small, and not easy to resolve.

M.57 (NGC 6720) *Lyræ*. RA 18^h 52^m, decl. +32°58′.
Figure K.

The planetary 'Ring Nebula'. I hesitated about including it in this list, as it is only of the 9th magnitude and so is very dim in a small telescope; but its position, midway between Beta and Gamma Lyræ, makes it very easy to find. The ring form is not so difficult to make out as might be thought. To me, it looks like a small, dimly-luminous cycle tyre! Distance, 1,400 light-years.

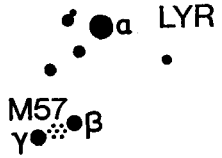


Figure K.

M.62 (NGC 6266) *Ophiuchi*. RA 16^h 58^m, decl. −30°03′.
Figure B.

A globular; integrated magnitude 6½, distance 22,500 light-years. Not far from Epsilon Scorpii. It is small but bright, and rather asymmetrical.

M.64 (NGC 4826) *Comæ*. RA 12^h 54^m, decl. −21°57′.
Figure A.

The 'Black-eye Galaxy'; a spiral at 44,000,000 light-years. As the integrated magnitude is above 7, this is one of the easier spirals to locate, though of course a small telescope will not show its form. It lies about one degree from the 5th-magnitude star 35 Comæ.

M.67 (NGC 2682) *Cancri*. RA 08^h 48^m, decl. +12°00′.
Figure J.

The famous old galactic cluster; 2,700 light-years from us. It is an easy binocular object near Alpha Cancri, and is a fine sight in a small telescope.

M.80 (NGC 6093) *Scorpii.* RA $16^h\ 14^m$, decl. $-22°52'$.
Figure B.

A globular cluster; magnitude $7\frac{3}{4}$, distance 36,000 light-years. It lies between Antares and Beta Scorpii, which makes it easy to find even though it is not really prominent. In 1860 a seventh-magnitude nova (T Scorpii) appeared in it, and for a brief period outshone the cluster itself.

M.81 (NGC 3031) *Ursæ Majoris.* RA $09^h\ 52^m$, decl. $+69°18'$.
Figure L.

A spiral galaxy; magnitude 8, distance over 8,000,000 light-years. A very famous radio galaxy; nearby is its fainter companion M.82, the 'exploding galaxy'. M.81 itself is not difficult to locate, near Fl.24 Ursæ Majoris, but, like all galaxies, it is very dim and disappointing in a small telescope.

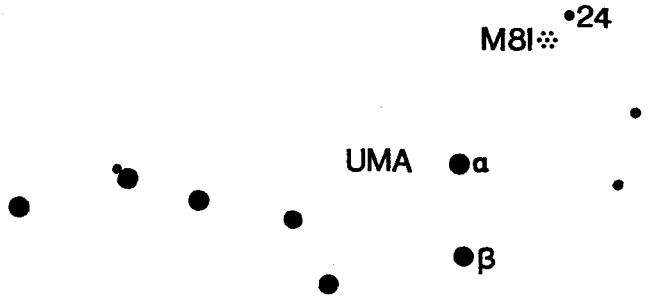


Figure L.

M.92 (NFC 6341) *Herculis.* RA $17^h\ 16^m$, decl. $+43°12'$.
Figure E.

A 6th-magnitude globular at 37,000 light-years. It lies between Iota and Eta Herculis, and is only slightly inferior to the great Hercules globular M.13.

These, then, are some of the more conspicuous of the Messier objects. Not everyone will agree with my selection, but at least it includes 'something for everybody'. The amateur with a somewhat more powerful telescope will have a great deal of pleasure in searching for, and finding, all the clusters and nebulæ in Messier's catalogue.

Some Interesting Telescopic Variable Stars

Star	R.A. h	R.A. m	Dec. °	Dec. ′	Mag. range	Period, days	Remarks
R Andromedæ	0	22	+38	18	6·1–14·9	409	
W Andromedæ	2	14	+44	4	6·7–14·5	397	
R Aquilæ	19	4	+ 8	9	5·7–12·0	300	
R Arietis	2	13	+24	50	7·5–13·7	189	
R Aurigæ	5	13	+53	32	6·7–13·7	459	
R Boötis	14	35	+26	57	6·7–12·8	223	
R Cassiopeiæ	23	56	+51	6	5·5–13·0	431	
T Cassiopeiæ	0	20	+55	31	7·3–12·4	445	
T Cephei	21	9	+68	17	5·4–11·0	390	
Omicron Ceti	2	17	− 3	12	2·0–10·1	331	Mira.
R Coronæ Borealis	15	46	+28	18	5·8–14·8	–	Irregular
W Coronæ Borealis	16	36	+37	55	7·8–14·3	238	
R Cygni	19	35	+50	5	6·5–14·2	426	
U Cygni	20	18	+47	44	6·7–11·4	465	
W Cygni	21	34	+45	9	5·0– 7·6	131	
SS Cygni	21	41	+43	21	8·2–12·1	–	Irregular.
Chi Cygni	19	49	+32	47	3·3–14·2	407	Near Eta.
R Draconis	16	32	+66	52	6·9–13·0	246	
R Geminorum	7	4	+22	47	6·0–14·0	370	
U Geminorum	7	52	+22	8	8·8–14·4	–	Irregular
S Herculis	16	50	+15	2	7·0–13·8	307	
U Herculis	16	23	+19	0	7·0–13·4	406	
R Hydræ	13	27	−23	1	4·0–10·0	386	
R Leonis	9	45	+11	40	5·4–10·5	313	Near 18, 19.
X Leonis	9	48	+12	7	12·0–15·1	–	Irregular (U Gem type).
R Leporis	4	57	−14	53	5·9–10·5	432	'Crimson star.'
R Lyncis	6	57	+55	24	7·2–14·0	379	
W Lyræ	18	13	+36	39	7·9–13·0	196	
HR Delphini	20	40	+18	58	3·6– ?	–	Nova, 1967.
LV Vulpeculæ	19	45	+27	2	4·8– ?	–	Nova, 1968.
U Orionis	5	53	+20	10	5·3–12·6	372	
R Pegasi	23	4	+10	16	7·1–13·8	378	
S Persei	2	19	+58	22	7·9–11·1	810	Semi-regular.
R Scuti	18	45	− 5	46	5·0– 8·4	144	
R Serpentis	15	48	+15	17	5·7–14·4	357	
SU Tauri	5	46	+19	3	9·2–16·0	–	Irregular (R CrB type).
R Ursæ Majoris	10	41	+69	2	6·7–13·4	302	
S Ursæ Majoris	12	42	+61	22	7·4–12·3	226	
T Ursæ Majoris	12	34	+59	46	6·6–13·4	257	
S Virginis	13	30	− 6	56	6·3–13·2	380	
R Vulpeculæ	21	2	+23	38	8·1–12·6	137	

Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to to be regarded as bona-fide doubles!

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Gamma Andromedæ	3·0, 5·0		060	Yellow, blue. B is again double (0".4) but needs a larger telescope.
Zeta Aquarii	4·4, 4·6	2·6	291	Becoming more difficult.
Gamma Arietis	4·2, 4·4	8	000	Very easy.
Theta Aurigæ	2·7, 7·2	3	330	Stiff test for 3 in. OG.
Delta Boötis	3·2, 7·4	105	079	Fixed.
Epsilon Boötis	3·0, 6·3	2·8	340	Yellow, blue. Fine pair.
Kappa Boötis	5·1, 7·2	13	237	Easy.
Zeta Cancri	5·6, 6·1	5·6	082	
Iota Cancri	4·4, 6·5	31	307	Easy. Yellow, blue.
Alpha Canum Venat.	3·2, 5·7	20	228	Yellowish, bluish. Easy.
Alpha Capricorni	3·2, 4·2	376	291	Naked-eye pair. Alpha again double.
Eta Cassiopeiæ	3·7, 7·4	11	298	Creamy, bluish. Easy.
Beta Cephei	3·3, 8·0	14	250	
Delta Cephei	var, 7·5	41	192	Very easy.
Xi Cephei	4·7, 6·5	6	270	Reasonably easy.
Gamma Ceti	3·7, 6·2	3	300	Not too easy.
Zeta Coronæ Borealis	4·0, 4·9	6·3	304	
Delta Corvi	3·0, 8·5	24	212	
Beta Cygni	3·0, 5·3	35	055	Yellow, green. Glorious.
61 Cygni	5·3, 5·9	25	150	
Gamma Delphini	4·0, 5·0	10	265	Yellow, greenish. Easy.
Nu Draconis	4·6, 4·6	62	312	Naked-eye pair.
Alpha Geminorum	2·0, 2·8	2	151	Castor. Becoming easier.
Delta Geminorum	3·2, 8·2	6·5	120	
Alpha Herculis	var, 6·1	4·5	110	Red, green.
Delta Herculis	3·0, 7·5	11	208	Optical double.
Zeta Herculis	3·0, 6·5	1·4	300	Fine, rapid binary.
Gamma Leonis	2·6, 3·8	4·3	121	Binary; period 400 years.
Alpha Lyræ	0·0, 10·5	60	180	Vega. Optical; B faint.
Epsilon Lyræ	4·6, 6·3	3	005	Quadruple. Both pairs separable in 3 in. OG
	4·9, 5·2	2·3	111	
Zeta Lyræ	4·2, 5·5	44	150	Fixed. Easy double.
Beta Orionis	0·1, 6·7	9·5	205	Rigel. Can be split with 3 in.
Iota Orionis	3·2, 7·3	11	140	

SOME INTERESTING CLUSTERS AND NEBULÆ

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Theta Orionis	6·0, 7·0 7·5, 8·0			The famous Trapezium in M.42
Sigma Orionis	4·0, 7·0 7·5, 10·0	11·1 12·9	236 085	Quadruple. D is rather faint in small apertures.
Zeta Orionis	1·9, 5·0	3	160	
Eta Persei	4·0, 8·5	8·5	300	Yellow, bluish.
Alpha Piscium	4·3, 5·3	1·9	291	
Alpha Scorpii	0·9, 6·8	3	275	Antares, Red. green.
Nu Scorpii	4·2, 6·5	42	336	
Theta Serpentis	4·1, 4·1	23	103	Very easy.
Alpha Tauri	0·8, 11·2	130	032	Aldebaran. Wide, but B is very faint in small telescopes.
Zeta Ursæ Majoris	2·3, 4·2	14·5	150	Mizar. Very easy. Naked eye pair with Alcor.
Alpha Ursæ Minoris	2·0, 9·0	18·3	217	Polaris. Can be seen with 3 in.
Gamma Virginis	3·6, 3·7	4·8	305	Binary; period 180 yrs. Closing.
Theta Virginis	4·0, 9·0	7	340	Not too easy.

Some Interesting Clusters and Nebulæ

Object	R.A.		Dec.		*Remarks*
	h	*m*	°	′	
M.31 Andromedæ	00	40·7	+41	05	Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41·3	+61	36	Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31·8	+30	28	Spiral. Difficult with small apertures.
H.VI 33–4 Persei	02	18·3	+56	59	Double cluster; Sword-handle.
M.1 Tauri	05	32·3	+22	00	Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33·4	−05	24	Great Nebula. Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06·5	+24	21	Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30·7	+04	53	Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45·5	−20	42	Open cluster, just visible to naked eye.
M.44 Cancri	08	38	+20	07	Præsepe. Open cluster near Delta Cancr Visible to naked eye.
M.97 Ursæ Majoris	11	12·6	+55	13	Owl Nebula, diameter 3′. Planetary.
M.3 Canum Venaticorum	13	40·6	+28	34	Bright globular.
M.80 Scorpionis	16	14·9	−22	53	Globular, between Antares and Beta Scorpionis.
M.4 Scorpionis	16	21·5	−26	26	Open cluster close to Antares.
M.13 Herculis	16	40	+36	31	Globular. Just visible to naked eye.
M.92 Herculis	17	16·1	+43	11	Globular. Between Iota and Eta Herculis.
M.7 Scorpionis	17	51·6	−34	48	Fine open cluster. Very low in England.
M.23 Sagittarii	17	54·8	−19	01	Open cluster nearly 50′ in diameter.
H.VI 37 Draconis	17	58·6	+66	38	Bright Planetary.
M.8 Sagittarii	18	01·4	−24	23	Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10·9	+06	50	Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18·8	−16	12	Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49·0	−06	19	Wild Duck. Bright open cluster.
M.57 Lyræ	18	52·6	+32	59	Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58·1	+22	37	Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02·1	−11	31	Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28·3	+12	01	Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31·0	+48	17	Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

PART FOUR

Miscellaneous

Some Recent Books

The Planets: some Myths and Realities, by Richard Baum. David & Charles, 1973. This is not an ordinary account of the planets; it deals specifically with some historical problems – such as the old observations of a satellite of Venus and a ring round Uranus. A fascinating book, useful to both layman and scholar.

The Cosmic Connection, by Carl Sagan. Doubleday, 1973. The quest for life beyond the Earth, discussed by one of the foremost researchers into this problem.

The Comets: Visitors from Space, by Patrick Moore. Keith Reid Ltd, 1973. A general account of cometary astronomy.

The Earth from Space, by J. Bodechtel and H. G. Gierloff-Emden. David & Charles, 1974. A beautiful collection of photographs from orbital and space vehicles, with a brief but good text.

The Next Ten Thousand Years, by Adrian Berry. Cape, 1974. An imaginative look into the future—from lunar bases to Dyson spheres!

Life among the Stars, by V. A. Firsoff. Wingate, 1974. "Man and the universe in an age of transition".

The Planet Mercury, by E. M. Antoniadi. The first English translation of this classic book, published in French in 1934. Mariner 10 has revised all our ideas about Mercury—but Antoniadi's book remains of tremendous historical interest.

Our Contributors

DR DAVID A. ALLEN was born in 1946, and educated at Manchester Grammar School and Cambridge University. He took his B.A. in theoretical physics in 1967, and his Ph.D. in 1971; the subject of his thesis was the infrared radiation of the unlit Moon. He took up a Carnegie Fellowship at the Hale Observatories from 1970 to 1972, and became a Junior Research Fellow at the Royal Greenwich Observatory in October 1972. His observing interests include infrared astronomy and low-resolution spectroscopy. His recent work has been concentrated on emission-line stars, and he has discovered several infrared sources. Telescopes used include the Palomar 200-in., the Mount Wilson 100-in., and 60-in., and the Isaac Newton 98-in.

DR C. H. BARROW is Senior Lecturer at the Department of Physics, University of the West Indies; he lives at Kingston, Jamaica. He is essentially a radio astronomer, and has carried out much original research; he spent some years in the United States at the Florida State University before moving to Jamaica. The radio emission from Jupiter is one of his special interests.

E. A. BEET was for many years Housemaster at the Nautical College, Pangbourne. He is the author of many books and papers, and has made important contributions to education in astronomy. He is a Past President of the British Astronomical Association, and is now Director of its Historical Section.

SIMON MITTON, M.A., Ph.D., M.Inst.P., is also a Cambridge graduate, and carried out research on radio galaxies until 1971. He is Secretary of the Institute of Astronomy at Cambridge, and is the U.K. editor of *Astrophysical Letters.*

F. R. SPRY is an amateur astronomer living at Selsey, where he has built his own observatory. He has given many lectures on amateur observatory construction, and contributed to the recent book *Astronomical Telescopes and Observatories for Amateurs.*

H. G. MILES, B.E.M., B.Sc., is a lecturer at the Lanchester College of Technology, Coventry. He is also Director of the Artificial Satellite Section of the British Astronomical Association, and in addition he specialises in meteor and meteorite research. He is the author of many scientific contributions, both technical and popular, and will be well-known to all readers of past *Yearbooks.*

Astronomical Societies in Great Britain

The advantages of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1966 *Yearbook;* a condensed list, suitably brought up to date, is given below.

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
British Astronomical Association	Burlington House, Piccadilly, London, W.1. (J. L. White)	£3·25 (§£2·50)	Burlington House, Piccadilly Last Wed. each month (Oct-June)
Junior Astronomical Society	58 Vaughan Gardens, Ilford, Essex	£1	Alliance Hall, Palmer St., WC1 *Last Saturday* Jan., April, July, Oct. 2.30 p.m.
Aberdeen and District Astronomical Society	14 Abbotshall Gardens, Cults, Aberdeen (W. P. Cooper)		Robert-Gordon's Institute of Technology, St Andrew Street, Aberdeen
Altrincham and District Astronomical Society	10 Delamere Road, Gatley, Cheadle, Cheshire (Colin Henshaw)	25p	Park Road Library, Timperley 1st Friday of each month 7.30 p.m.
Aylesbury Astronomical Society	9 Elm Close, Butler's Cross, Aylesbury (N. Neale)	£1	As arranged
Birmingham Astronomical Society	17 Hannafore Road, Edgbaston, (W. E. Marsh)	£1 (§25p)	Birmingham and Midland Institute Monthly
Bridgwater Astronomical Society	The Bridgwater College, Broadway, Bridgwater, Somerset (W. L. Buckland)	70p (§35p)	A.T.C. H.Q., Rope Walk, Bridgwater, 3rd Tuesday in each month. Sept.-June
Brighton Astronomical Society	Flat 2, 23 Albany Villas, Hove, Sussex, BN3 2RS (Mrs B. C. Smith)	£1(§50p)	Preston Tennis Club, Preston Drive, Brighton. Weekly. Tuesdays.
Bristol Astronomical Society	34 Butterfield Close, Bristol BS10 5AZ (G. H. Woodman)	£2·50 (§52½p)	Royal Fort (Rm G44) Bristol University last Friday each month, Sept.-May
Caithness and Dounreay Astronomical Society	Room 31, Ormlie Lodge, Thurso, Scotland (Miss M. J. A. Clark)	£1	Fortnightly
Camberley (Surrey) Astronomical Society	75 Christchurch Drive, Blackwater, Surrey (Ron Toft)	50p (§20p)	Adult Education Centre, France Hill Drive, Camberley, Surrey. Monthly
Cambridge Astronomical Society	5 Haggis Gap, Fulbourn (S. R. Whistler)	£1·05 (§37½p)	7 Brooklands Avenue, Cambridge 2nd Mon. each month Oct.-July
Chelmsford and District Astronomical Society	70 Maldon Road, Burnham-on-Crouch (Miss C. C. Puddick)	£1 (§50p)	Sandon House School, Chelmsford Last Mon. in month 7.30 p.m.

Name	*Secretarial Address*	*Yearly Subscription* §=members under 18, or 'juniors'	*Meeting Time and Place*
Chester Astronomical Society	37 Alwyn Gardens, Upton, Chester (A. Kemp)	£1 (§50p)	St Andrews House, Newgate St., Chester Monthly
Chester Society of Natural Science, Literature and Art	Wood Farm, Tattenhall Lanes, Tattenhall, nr Chester (Geoffrey Lake)	—	Grosvenor Museum, Chester Fortnightly
Chesterfield Astronomical Society	Hilltop Cottage. Gallery Lane, Holymoorside, Chesterfield (Mrs R. C. Naylor)	£1 (§50p)	Barnett Observatory, Newbold Each Friday
Clackmannanshire Astronomical Society	9 Deer Park, Sauchie, Alloa (J. Cluckie)	£1	St Mary's School, Alloa Monthly, 3rd Friday Sept.-May
Clacton & District Astronomical Association	105 London Road, Clacton-on-Sea, Essex (C. L. Haskell)	—	—
Cleethorpes Astronomical Society	95 Sandringham Road, Cleethorpes, Lincolnshire (W. S. Cobley)	£1 (§50p)	Dolphin Hotel, Cleethorpes Monthly
Crawley Astronomical Society	27 York Road, Crawley Sussex (A. Drummond)	£1(§50p)	Crawley College of Further Education Monthly Oct-June
Crayford Manor House Astronomical Society	Manor House Centre, Crayford, Kent (R. H. Chambers)	None	Manor House Centre, Crayford Monthly during term-time
Croydon Astronomical Society	12 Elstan Way, Shirley, Croydon (K.E. Stanbridge)	— 5p entrance fee to meetings	The Old Whitgiftian Sports Club, Lime Meadow Ave., Sanderstead, Surrey Alternate Fridays 7.45 p.m.
Derby and District Astronomical Society	The Hollies, Croft Lane, Breadsall, Derby (F. Shaw)	£1·50 (§50p)	1st Friday each month, at The Hollies
Dundee Astronomical Society	80 Torridon Road, Broughty Ferry, Dundee (K. Kennedy)	50p (§25p)	Mills Observatory, Dundee Fortnightly in the winter
Eastbourne Astronomical Society	Flat 3, 17 Hartfield Road, Eastbourne (T. Allchin)	£1·50 (§75p)	As arranged Monthly
East Lancashire Astronomical Society	16 Worston Lane, Great Harwood, Blackburn, BB6 7TH (D. Chadwick)	£1·50 Juniors, etc. 75p	As arranged Monthly
Astronomical Society of Edinburgh	126 W. Saville Terrace, Edinburgh 9, Scotland (N. G. Matthew)	£1	Calton Hill Observatory. Edinburgh Monthly
Ewell Astronomical Society	11 Elmwood Drive, Ewell, Surrey (L. J. Bentley)	£1 (§50p	Ewell County Technical College, Reigate Road, Ewell, Surrey 1st Friday of each month
Fellowship of Junior Astronomers, Edinburgh	58 Ogilvie Terrace, Edinburgh 11, Scotland (Miss Edith McLean)	50p	Calton Hill Observatory, Edinburgh 3rd Fri. each month, Sept.-June
Fylde Astronomical Society	28 Belvedere Rd, Thornton, Lancs (—)	£1 (§50p)	Stanley Hall, Rossendale Ave. South 1st Wed. each month

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Astronomical Society of Glasgow	8 Kirkoswald Road, Newlands, Glasgow (H. Palmer)	£1 (§50p)	Roy. Coll. Science and Tech., Glasgow 3rd Thur. each month, Sept.-April
Great Yarmouth Astronomical Society	38 Cobholm Road, Cobholm, Great Yarmouth, Norfolk (M. Poxon)	To be announced)	(To be announced)
Guildford Astronomical Society	12 Durham Close, Guildford (Mrs. D. E. Clapson)	£1	Corona Restaurant, High Street, Guildford 1st Tue. each month 7.45 p.m.
Astronomical Society of Haringey	58 Stirling Road, Wood Green, London, N22 (W. T. Baker)	50p(§20p)	673 Lordship Lane, Wood Green, London, N22 3rd Thurs. each month 7.30 p.m.
Herschel Society	35 Kendal Drive, Slough (C. Wise)	—	(To be announced)
Isle of Wight Astronomical Society	1 Hilltop Cottages, High Street, Freshwater, Isle of Wight (J. W. Feakins)	£1 (§50p)	Unitarian Church Hall, Newport, Isle of Wight Monthly
Leeds Astronomical Society	Maths. Dept., The University, Leeds 2 (B. L. Meek)	50p (§25p)	Leeds University Six annually
Leicester Astronomical Society	26 Falmouth Rd., Evington, Leicester (Mrs L. Withey)	£1·05 (37p)	Leicester Museum and Art Gallery Monthly
Lincoln Astronomical Society	344 Brant Road, Lincoln (P. Hammerton)	£1 (§25p)	Lincoln YMCA Hall 1st Tue. each month
Liverpool Astronomical Society	Simms Cross School Hse., Mitton Road, Widnes (D. Bradburne)	£1·50 (§75p)	City Museum, Liverpool Monthly
Loughton Astronomical Society	6 Baldock Road, Theydon Bois, Epping, Essex (S. Smith)	£1·50 (§£1)	Loughton Hall, Rectory Lane, Loughton, Essex Thursdays, 8 p.m.
Luton Astronomical Society	20 Bloomfield Avenue, Luton (S. J. Anderson)	£1	Last Friday each month
Lytham St. Annes Astronomical Association	141 Blackpool Road, Ansdell, Lytham St. Annes, Lancs. (K. J. Porter)	50p(§25p) + 5p per meeting	College of Further Education, Clifton Drive S., Lytham St. Annes 2nd Wed. monthly Oct.-June
Maidenhead Astronomy Group	129 Fane Way, Maidenhead, Berkshire (S. A. H. Roper)	50p (§12½p)	Maidenhead Grammar School Once every 3 weeks
Manchester Astronomical Society	Cragside, Cliff Avenue, Summerseat, Bury (Alan Whittaker)	£1 (§50p)	Godlee Observatory, Manchester 1 Weekly
Mansfield and District Astronomical Society	14 Bonnington Crescent, Sherwood Estate, Nottingham (G. W. Shepherd)	50p (§25p)	Monks Precision Engineering Co., Mansfield Rd., Sutton-in-Ashfield Last Monday of each calendar month

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Mid-Sussex Astronomical Society	19 Blackthorns, Lindfield, Sussex (G. A. N. Molloy)	£2 (§£1)	Haywards Heath Grammar School Wednesdays 7.30 p.m.
Milton Keynes Astronomical Society	26 Betty's Close, Newton Longville, Milton Keynes, MK17 0AN (Paul D. Keen)	10p (§5p) per meeting £1	Alternate Tuesdays
Newcastle-on-Tyne Astronomical Society	30 Kew Gardens, Whitley Bay, Northumberland (G. E. Manville)	£1	Botany Lecture Theatre Newcastle University Monthly, Sept.-April
Newtonian Observatory Astronomical Society	62 Northcott Road, Worthing, Sussex (Miss P. E. Randle)	£1·20	Adult Education Centre Union Place, Worthing 1st Wed. each month except Aug. 7.30 p.m.
North Devon Astronomical Society	Arafat, 18 The Shields, Ilfracombe, North Devon (R. W. Rose)	Details to be announced later	
North Dorset Astronomical Society	The Pharmacy, Stalbridge, Dorset (J. E. M. Coward)	—	Charterhay, Stourton, Caundle, Dorset 2nd Wed. each month
Norwich Astronomical Society	The Manse, Back Lane, Wymondham, Norwich (Rev. Cyril D. Blount)	£1 (§50p)	Norwich Observatory, Colney Lane, Cringleford, Norwich Every Tues. and Sat. Public meetings 3rd Sat. at Spinney Community Centre
Nottingham Astronomical Society	18 Naseby Close, Heathfield, Nottingham (C. Swift)	£1·25p	Monthly
Orion Astronomical Society	11 Hunter Place, Louth, Lincolnshire (T. P. Byatt)		Details to be announced
Orwell Astronomical Society (Ipswich)	33 Crofton Road, Ipswich, Suffolk (M. Hadden)	£1·05 (§5p	Orwell Park School Nacton, Ipswich Weekly
Oxshott Astronomical Group	Norman Cottage, Pond Piece, Sheath Lane, Oxshott, Surrey (E. H. Noon)	50p	Oxshott Village Centre 1st Wed. each month Sept.-May
Paisley Astronomical Society	14 Cheviot Avenue, Barrhead, Glasgow (Mrs J. Holms)	£1 (§50p)	Coats Observatory, 49 Oakshaw Street, Paisley Monthly
Peterborough Astronomical Society	24 Cissbury Ring Werrington, Peterborough (E. Pitchford)	£1·25 (§25p)	Peterborough Technical College 2nd Tues., 3rd Thur. each month
Phoenix Astronomical Society	38 Myers Avenue, Bolton, Bradford 2, Yorks. (B. Jones)	—	Phoenix Park Sports Club, off Dick Lane, Thornbury, Bradford 3.
Plymouth Astronomical Society	1 Valletort Cotts, Millbridge, Plymouth (G. S. Pearce)		Plymouth College of Technology, Tavistock Road, Plymouth Monthly
Portsmouth Astronomical Group	52 Denbigh Drive, Fareham, Hampshire (S. W. Hackman)	£3	The Group Observatory

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Portsmouth Astronomical Society	91 Sutherland Road, Southsea (P. R. Seiden)	£1·50	Monday Fortnightly
Preston and District Astronomical Society	35 Bispham Road, Carleton, Poulton-le-Fylde, Lancs (C. Lynch)	£1 (§25p)	Chamber of Commerce, 49a Fishergate, Preston 3rd Mon. each month Sept.-May
Rayleigh Centre Amateur Astronomical Society	18 Tickfield Avenue, Southend-on-Sea, Essex (N. McCouat)	£1·50 (80p)	Fitzwimarc School, Hockley Road, Rayleigh. Every Wed., 8 p.m.
Reading Astronomical Society	30 Amherst Road, Reading (J. Wrigley)	75p (§25p)	Anderson Baptist Church Hall, Reading Monthly
Salford Astronomical Society	44 Pevensey Road, Salford 6 (A. Taylor)	£1 (§50p)	The Observatory, 3rd Wed. each month
Salisbury Plain Astronomical Society	St George's Cottage, Orcheston, Salisbury, Wilts. (R. J. D. Nias)	50p (§25p)	St George's Rectory Orcheston Quarterly
Slough Astronomical Society	The Elms, Odds Farm, Green Common Lane, Wooburn Common, High Wycombe, Bucks (E. Shilton)	£1	Monthly
Solent Amateur Astronomers	14 Orchard Avenue, Bishopstoke, Eastleigh, Hants. (R. W. Arbour)	£1·50 (§75p) certain students 50p	Room 33, Library Block, Southampton University. 3rd Thur. each month. 7.30 p.m.
South Downs Astronomical Society	32 Birdham Close, Stroud Green, Bognor Regis (Mrs Buss)	£2 (§£1)	Last Friday in each month
Southampton Astronomical Society	4 Heathfield, Dibden Purlieu, Southampton (J. G. Thompson)	£2 (§£1)	2nd Thur. each month Unigate Conference Room, Southampton 4th Thursday each month Room 33, University of Southampton
Southport Astronomical Society	37 Park Avenue, Southport PR9 9EF (Malcolm Thomas)	75p	As arranged Monthly
South Shields Astronomical Society	Marine and Technical College, St George's Ave., South Shields, Co. Durham (H. Haysham)	£1 (37½p)	Marine and Technical College Each Thursday, 7.30 p.m.
South West Herts Astronomical Society	32 Riverford Close, Harpenden, Herts. (G. J. B. Phillips)	£1·50 (§75p)	Royal Masonic School for Girls, Rickmansworth Last Fri. each month Sept.-May
Stoke-on-Trent Astronomical Society	Sundale, Dunnocksfold Road, Alsager. Stoke (M. Pace)	75p	Cartwright House, Broad Street, Hanley Monthly
Swansea Astronomical Society	30 Cwrt-y-Clafdy, Skewen, nr Neath, Glamorganshire (C. Morris)	£1·50 (§25p) Students 50p	As arranged
Thanet Amateur Astronomical Society	85 Crescent Road, Ramsgate (P. F. Jordan)	25p	Hilderstone House, Broadstairs, Kent Monthly

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Torbay Astronomical Society	4 Heath Rise, Brixham, Devon (Miss A. Longman)	75p (§25p)	Quay Tor Hotel, Scarborough Road, Torquay. Monthly
Waltham Forest and District Junior Astronomy Club	24 Fulbourne Road, Walthamstow, London E17 (B. Crawford)	50p	24 Fulbourne Road, Walthamstow, London E17 Fortnightly (Mondays)
Warrington Astronomical Society	2 Dale Avenue, Appleton, Warrington (B. P. Rees)	£1	Central Library, Museum Street, Warrington, Lancs Monthly, Sept.-May
Warwickshire Astronomical Society	20 Humber Road, Coventry, Warwickshire (R. D. Wood)	£4	20 Humber Road, Coventry Each Tuesday
Webb Society	7 Elvendon Road, Palmers Green, London, N.13 (E. Moore)	£1 (§75p)	As arranged
Wessex Astronomical Group	St Catherine's Court, D4, 35 Christchurch Road, Bournemouth (Mrs H. Bagainy)	—	Ashley Cross Girls School, Lower Parkstone, Poole, Dorset 1st Tues. each month (except Aug.) 7.30 p.m.
West of London Astronomical Society	5 Blakesley Avenue, Ealing, W5 2DN (P. Macdonald)	40p	Monthly, alternately at Ruislip and North Harrow 2nd Monday of the month (except August)
West Yorkshire Astronomical Society	76 Katrina Grove, Purston, Pontefract, Yorks. WF7 5LW (J. A. Roberts)	50p (§25p) entrance fee 75p (§25p)	The Barn, 4 The Butts, Back Northgate, Pontefract Every Tues. 7 p.m.
Wolverhampton Astronomical Society	Garwick, 8 Holme Mill, Fordhouses, Wolverhampton (M. Astley)	Under 18- 40p Over 18- £1·50 Joint Sub. Man & Wife- £2·50 Retired persons- 50p	Polytechnic, Wulfruna Street, Wolverhampton Alternate Mon., Sept.-April
Wyvern Astronomical Society	2 Howcroft, Churchdown, Gloucester (A. F. Edwards)	75p (§25p)	Clubhouse, Churcham Last Friday of each month except Aug.
York Astronomical Society	1 Low Catton Road, Stamford Bridge, York. (Mrs J. Acton)	£2 (§£1)	York Railway Institute. Fortnightly Fridays.
Zenith Astronomical Society	10 Meadow Close, Reedby, nr Burnley (A. Harvey)	—	54 Cromwell Street, Burnley 1st Wednesday in each month

It is possible that this list of local societies may not be quite complete. If any have been omitted, or any details need to be updated, the secretaries concerned are invited to write to the Editor (c/o Messrs Sidgwick & Jackson (Publishers), Ltd, 1 Tavistock Chambers, Bloomsbury Way, London WC1), so that the relevant notes may be included in the 1976 *Yearbook*.

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